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Remote Sensing of Geobotanical Relations in Georgia

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REMOTE SENSING OF

GEOBOTANICAL RELATIONS IN GEORGIA

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Project Title: Research Study "Geological-Vegetative Relationships (Botanical)"

Contract No.: NAS8-30884

Contractor: Georgia Southwestern College
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PREFACE

The accompanying report describes the results of a research study, "Geological-Vegetative Relationships (Botanical)", conducted by the writers during the period September 1974 through December 1976, under NASA contract NAS8-30884. The study was monitored by the Earth Resources Office, Marshall Space Flight Center, Alabama.

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I. SUMMARY

The principal objective of the study was to evaluate the application of remote sensing to geological investigations, with special attention to geobotanical factors. The influence of geology on vegetation has been recognized for centuries, but systematic studies of the relationships are relatively recent; most literature on the subject has appeared during the past 40 years. Our projects were designed to seek any geologic-vegetative relationships that might occur but also to find techniques by which they could be identified by remote sensing methods.

The study was primarily related to investigations in Georgia, but the various projects represent a diversity of geological situations and are typical of conditions in the southeastern United States, where abundant year-around rainfall and deep soil cover are the rule.

A review of present knowledge of the use of indicator plants for mineral prospecting and other geological applications is included, along with a discussion of remote sensing techniques in botanical studies. Russian workers have been active in geobotanical mapping, while Australian and North American investigators have successfully utilized indicator plants in locating mineral deposits, although neither group has exclusive claim in any area of application.

Various types of remote sensing materials were obtained for the study. Landsat imagery in several scales and formats were used, including the largest color prints available from the Eros center; black-and-white prints of all bands; and both positive and negative 70-mm transparency chips. Photographic media were from Skylab, high-altitude reconnaissance, and conventional aerial photo missions. Two MSFC flights provided winter and spring coverage,

utilizing color infrared and 4-lens multispectral photography. Of all media, the color infrared was the most useful for detailed analysis.

A. Gladesville Norite Project

Norite, a variety of gabbro, intrudes metamorphic rocks dominated by hornblende gneiss. The norite contains pegmatite veins which are mined for their feldspar content. Three diabase dikes, presumably of early Mesozoic age, intrude norite and country rock. The geology of the area is well described; the boundaries of the norite body, hornfels contact metamorphic zone between it and the country rock, and location of pegmatite and diabase intrusions are mapped. A geochemical survey has plotted concentrations of copper, zinc, and nickel.

Careful field work and laboratory treatment of remote sensing material has failed to reveal any botanical indications of the mineralization, and so we conclude that insufficient chemical differences exist to affect the vegetation in this area of deep soil.

B. Pine Mountain Area

This area of metamorphic and intrusive rocks at the southern end of the Piedmont province is bounded by major thrust faults with wide milonite zones. Here the metasediments, granitic intrusions, and cataclastic milonite belts are sufficiently different in chemical make-up and weathering characteristics to influence the vegetation. As a consequence, fault zones and certain formations, especially the Hollis Quartzite, show up well on all remote sensing documents. We recommend further work to define the tonal signature for each geological formation.

C. Dougherty County Sinkhole Problem

Albany is one of the fastest growing cities in Georgia. It is

located on the Dougherty plain, a region underlain by cavernous limestone. Sinkholes tend to accompany urban expansion and proliferate as the water table is lowered. Lowering of the water table causes plant stress in cavernous areas where sinks are likely, so recognition of this condition of reduced moisture is a clue to collapse. Color infrared photography was used for analysis. We have developed a procedure for microgravity surveying which shows promise of verifying the CIR vegetation-stress interpretation by revealing the pattern of limestone caverns.

D. Andersonville Kaolin District

The possibility that there was a relationship between the relative abundance of Turkey Oak and Short-leaf Pine and the presence of kaolin bodies was investigated. It was concluded that soil and topographic factors are the most important controls, and buried kaolin cannot be detected by surface observations.

In studying the CIR photography a number of linear trends were noted in the vegetation, suggesting fault control. Field investigation of a linear cypress swamp revealed a scarp in the Flint River terrace deposits which corresponds with a fault found earlier in 1976 during a reflection seismic traverse of a portion of the river. Evidence is strong for 2 or 3 fracture sets and vertical faulting, with the upthrown side to the south, on which movement occurred during Holocene time.

II. INTRODUCTION

A. Objectives

A relationship between the occurrence of certain plants and the presence of rock or mineral types was recorded in the folklore of many societies long before there was systematic investigation of this phenomenon. As

the physiological and ecological controls became better known and a body of literature developed which catalogued the various specific occurrences, recognition techniques became a part of the research process, and remote sensing methods were quickly adopted as an important aspect of this work.

The principal objective of the present investigation is to evaluate the applicability of remote sensing techniques to recognition of geobotanical relationships in the southeastern United States, where extensive weathering and deep soil cover present problems of geological recognition that are different from those found in regions where bedrock is widely exposed.

This is basically a feasibility study, and was designed to evaluate several remote sensing methods as they might be applied to various aspects of geological investigation. Within the limitations of time and budget, we have selected a diversity of projects representing different aspects of geology. The general areas of investigation included: (1) recognition of mineral deposits; (2) geological mapping; (3) delineation of geological structure, including areas of complex tectonics as well as the Coastal Plain belt where faulting may be very recent but quite difficult to recognize; (4) limestone areas where ground water withdrawal has intensified surface collapse.

B. Scope of Investigations

Four project areas were selected for detailed investigation and several other areas were visited and tentatively evaluated (Fig. 1). Two of the detailed projects concerned recognition of geological differences along discrete formational boundaries (Gladesville and Pine Mountain), one investigated possible surface expression of buried clay bodies and faults

(Andersonville), and the fourth was related to criteria for recognizing plant stress due to water deprivation and verifying by geophysical methods that such deprivation was due to limestone caverns that were sites of potential sinkholes (Albany). The other localities were sites that appeared as anomalous areas on imagery or aerial photographs, or had been recognized as geologically and botanically distinctive during the course of related field operations.

Color infrared (CIR) and 4-lens multispectral aerial photography was flown by an aircraft operating from Marshall Space Flight Center. This photography plus a variety of photography and Landsat imagery obtained from Eros center provided the fundamental remote sensing resource material for the investigations. Analysis of these film documents and ground checks supplemented by laboratory work constituted the general analytical procedure. We feel that each of the four principal projects was sufficiently investigated to evaluate the applicability of remote sensing to the specific problem. Results and recommendations are included in the discussion of the individual areas.

C. Review of Investigation Methods

Geology. The geology was generally known in each project area, so geological investigation consisted principally of transferring information from existing maps and reports to 1:24,000-scale topographic maps and field checking the accuracy of the data. In several instances, especially in the Gladesville and Pine Mountain areas, adjustments in geological contacts and rock descriptions were made. Often these adjustments were first recognized on the remote sensing documents and verified by field work. Mineral and rock identification was checked by thin section and other analysis in the laboratories at Georgia Southwestern College.

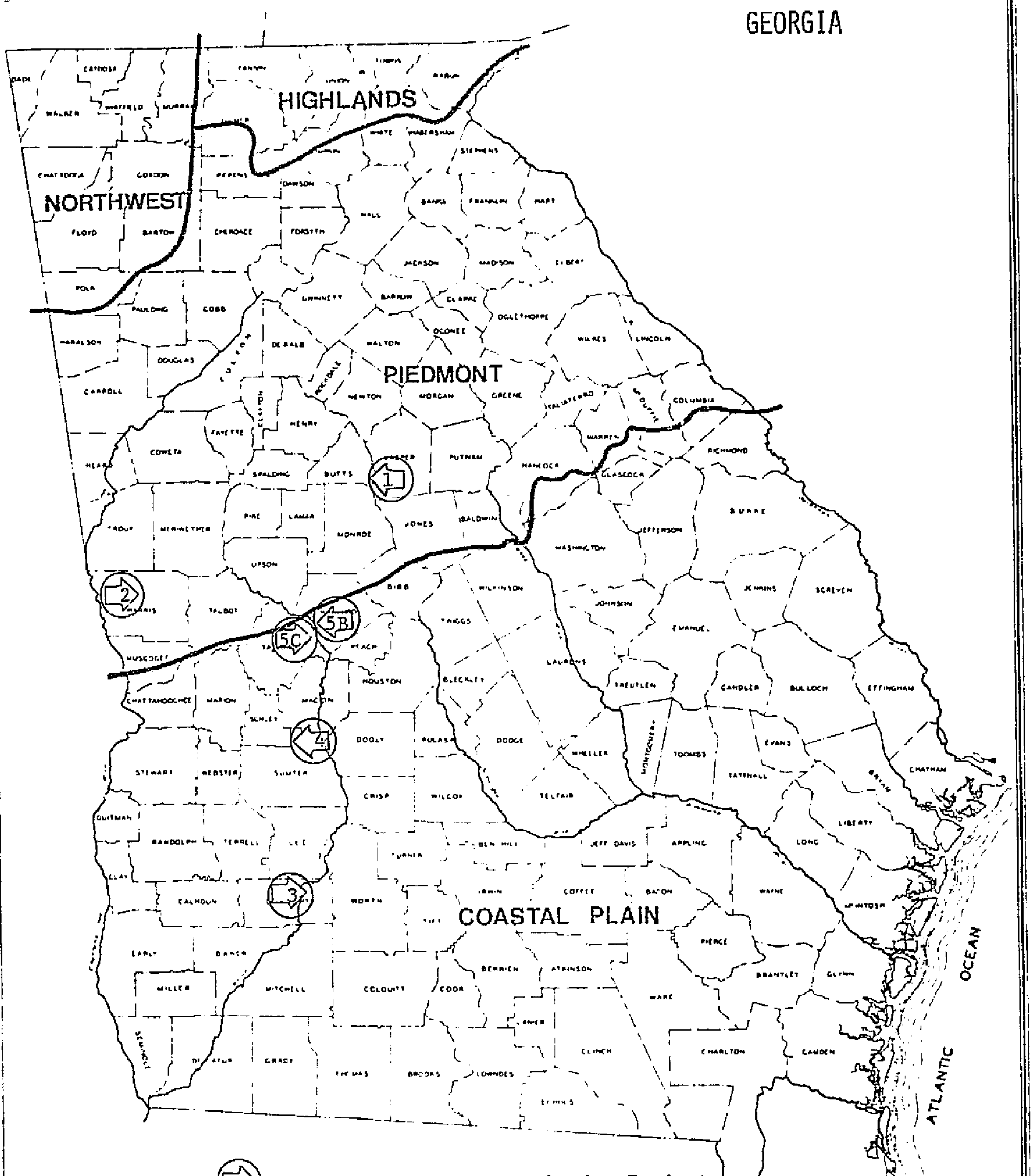

Fig. 1 - Location Map Showing Project Sites

Field checks of several linear features noted on photographs of the Andersonville area supported the idea that these were related to jointing and vertical faulting. Photographs and imagery revealed possible sinkhole locations around Albany. A sufficient number were examined by ground observation and geophysical methods to verify the interpretations.

Longer lineaments have been noted on the Landsat imagery, but field checks to verify their nature are beyond the scope of the present projects.

Vegetation analysis. Botanical traverses were made at selected intervals, and were generally designed to transect geological trends. Collecting and observational procedure varied from area to area, the details of which are described and illustrated in the discussions of the individual areas.

Most often the botanical analysis included a traverse grid wherein the grid intersections served as observation sites. These provided regularly spaced data points for the construction of vegetation maps. Field observations were made to verify photointerpretation and to establish ground truth for vegetation maps derived from photography and other imagery.

Imagery and photography. Landsat imagery and a variety of aerial photography were examined. The research facilities of the Eros center at Bay St. Louis, Mississippi, were visited, where remote sensing documents were viewed and computer print-outs of available coverage were obtained. Equipment at Marshall Space Flight Center (MSFC) was also utilized, especially the I^2S (International Imaging Systems) viewer. The viewer was used with Landsat 4x4-inch chips, in both positive and negative film format, and many combinations of imagery bands and color filters were examined.

Color slides of these composites were made with tripod-mounted 35-mm camera. The slides could be enlarged by projection and examined in detail without further recourse to the I^2S equipment, thus allowing the material to be viewed almost anywhere.

During the course of the project three aerial photographic missions were accomplished by aircraft under contract to MSFC. Flights were made in winter, spring, and fall in order to view the vegetation under all conditions of foliage change. Color infrared and multispectral photography was taken simultaneously along most of the lines of the winter and spring missions, and multispectral only was exposed on the fall flight.

Geophysics. The Albany sinkhole project differed from the other investigations in that the problem was not one of identifying different geological units but rather to verify that plant stress recognized by remote sensing was related to caverns which might collapse and become sinkholes. Such relations have been recognized elsewhere (e.g., at Greenwood, Alabama, described by Newton et al., 1973) but verification of the caverns required drilling. We have used a Worden gravity meter, combining closely spaced gravity readings and accurate elevation control to prepare a computer-generated microgravity model that has resulted in successful identification of potential sinks.

III. CONCLUSIONS AND RECOMMENDATIONS

A. Applicability of Remote Sensing to Geobotanical Investigations

The relationship of certain plants to rock and mineral occurrence is discussed elsewhere in this report. Such relationships demonstrably exist and are largely, though not exclusively, due to chemical factors. The present investigation is concerned with how the geobotanical correlations can

be identified by remote sensing techniques, and as a further qualification, how the techniques might be applied in the southeastern United States. Four specific categories of application were investigated in detail and three others were pursued to the point of recommending the feasibility of further work. Success was mixed, and the results did not always confirm the anticipated outcome. New approaches developed during the progress of some projects, and efforts to solve a problem lead to techniques not envisioned in the original plans. This is especially evident in the Dougherty County sinkhole investigations, where remote sensing recognition of plant stress symptoms, combined with microgravity surveys, has promise of a rapid and inexpensive means of evaluating the collapse potential of land under development.

A review of the results of each project follows:

1. Gladesville Norite

This project involved attempted recognition of a relatively large intrusive igneous body which contains some metallic minerals and has itself been mineralized by pegmatite intrusions. Although some geochemical anomalies are known to exist in the area, we could recognize no vegetative indicators, either on the ground or from any remote sensing medium.

The norite intrudes metamorphic country rock which is dominantly hornblende gneiss. Apparently, in the central Georgia climate with its deep soil development, any chemical differences are obscured and there is no recognizable effect on the vegetation. A diabase dike can be traced on 1:24,000-scale CIR photography. Ground check indicates that trees are not common on the trace of the dike, perhaps because of the thin soil that is present.

2. Pine Mountain area

This is an area of metamorphic rocks bounded by major faults involving wide zones of cataclastic rocks. The chemistry and weathering characteristics of the rocks are both variable factors. Weathering differences result in well-defined topographic expression of some lithologic units, which in turn influences vegetation. The result is that the combination of topography and chemistry makes certain rock types readily identifiable by remote sensing techniques.

3. Dougherty County sinkhole area

Remote sensing is applicable to recognition of vegetation stress brought on by a lowered water table in an area of caverns. Critical lowering of the water table is a major factor in sinkhole occurrence. We have demonstrated that the vegetation stress analysis can be confirmed by a microgravity survey. We believe this to be the first application of gravity surveys to locate potential limestone collapse in the southeastern United States, although the method has been in use for a decade in Europe.

4. Andersonville kaolin district

A preference of some species of trees for certain soil characteristics can be shown in the Andersonville district, and undoubtedly exists throughout the distribution range of the species. However, no direct correlation between subsurface kaolin bodies and vegetation could be found. As elsewhere, it is the physical and chemical factors of soil, slope, sunlight, and moisture that control the plant cover.

While the Andersonville investigations did not reveal any methods of identifying buried kaolin, we were amazed to find that many linear features were recognizable on the CIR and multispectral 1:24,000

scale photographic coverage obtained by MSFC. The linears show up in the topography and the vegetation. Ground investigation indicates there is a joint and fault pattern much more extensive than previously suspected. Movement on up-to-the-south faults has been so recent that fault scarps are still present which have acted as dams against the southward-dipping sediments. At least one linear swamp was recognized on photographs and its probable fault origin confirmed by ground study.

5. Summary of applicability studies

The various projects have provided a broad analysis of a variety of geobotanical relationships in Georgia. Each has unique but widely applicable characteristics. The following generalizations can be made, stipulating that they relate to conditions in central Georgia and can be considered applicable to areas of generally equivalent climate in the southeastern United States.

a. Differences in vegetation population can be recognized by remote sensing methods. The ratio or degree of difference that can be reliably recognized is a function of the map scale of the photography or imagery and of the method.

b. Factors having significant control on vegetation are soil and bedrock chemistry, topography, slope as a factor in drainage and sunlight, and moisture retention.

c. Where relatively sharp boundaries between any of the control factors exist, plant differences will probably be recognizable.

d. Unless intrusive mineral bodies are chemically distinct from the country rock to the extent that the differences are reflected in the soil cover, the presence of the intrusive cannot be detected by any remote sensing techniques available to us in this study.

e. There appears to be no relationship between vegetation and subsurface clay bodies in the Coastal Plain. On the other hand, limestone at the surface may be well-defined by its plant cover.

f. With proper techniques, potential collapse sites in cavernous limestone areas can be predicted by remote sensing methods.

g. Jointing and faulting in the Coastal Plain appears to be active, and creates surficial linears that are reflected in topography and vegetation.

B. Recommendations

The projects undertaken during this investigation were new to the region and can be considered essentially as feasibility studies. Three separate approaches in the application of remote sensing to geological questions were investigated and appear to be worth pursuing further. One project was not successful and we can recommend no new techniques that might give better results. This is the Gladesville Norite project. It appears that there is no readily recognizable relationship between mineralization and vegetation, at least in the Georgia Piedmont province.

The three projects that point to useful applications are discussed here individually in terms of recommendations as to how their apparent feasibility can best be verified and put to use.

1. Sinkhole problem

The recognition of plant stress due to water deprivation verification by microgravity of the presence of caverns has promise of widespread application in predicting potential sinkhole occurrence.

We have surveyed two areas and have found that known sinks correlate with gravity anomalies. We now need to check an area where sinks

have not yet appeared but where signs of vegetation stress suggest this may be imminent. If gravity anomalies are indicated, a "collapse-potential" map can be made. The final test would be to verify one or more anomalies by drilling.

As of this writing, in January 1977, we have completed arrangements with the management of the Albany (Georgia) Municipal Airport to begin a survey on the airport property. Sinks have occurred in the area and are an important consideration in a pending decision to move the municipal air terminal to the site of Turner Field, a former military air station closed in 1976. The Georgia Geological Survey has a drilling rig operating in the vicinity of Albany, and we hope that one or two test holes can be scheduled before this equipment is moved to a different assignment.

2. Coastal Plain structures

The extent of seismic activity in the southeastern United States has only recently been recognized. A number of monitoring stations have been established within the past decade (Moore and Jones, 1976) including two stations in Georgia, Station AMG at Georgia Southwestern College and one near Atlanta operated by Georgia Institute of Technology. The Charleston, South Carolina, earthquake of 1886 was the most severe manifestation in historic times, but seismic events of lesser magnitude are recorded every year. A Coastal Plain fault with evidence of very recent activity near Augusta, Georgia, has been examined by U.S. Geological Survey personnel (Prowell, et al., 1975).

Our work in the Andersonville district has helped to confirm the fault described by Zapp (1963) and Jones (1976). Two, and possibly three, fracture sets can be traced on the basis of topographic and vegetative lineaments.

The fault pattern seems to be vertical and dominantly with the upthrown side to the south. This sometimes results in the juxtaposition of impervious clays on the south against water-bearing sands, which forms an effective dam and creates swamps with a linear southern boundary.

A 10-km reflection-seismic line was run on the Flint River in 1976 to verify the Andersonville fault. The line crossed three faults in addition to the one sought. We recommend (1) that the river seismic work be extended in both directions; (2) gravity profiles be run parallel to the seismic lines; and (3) the entire river area, for a distance of 15 km on either side, be photographed by color infrared method at a scale of 1:24,000 or larger.

3. Tonal signatures on Landsat prints

It is apparent that various reflectance tones on the Landsat imagery correspond to specific geological formations. For example, comparison of Landsat prints and the 1:500,000-scale geological map (Georgia Geological Survey, 1976) in the area of the upper Coastal Plain between the Chattahoochee and Ocmulgee Rivers, shows close correlation between the pattern of geological formations on the map and recognizable tones on the imagery. This is especially true of the Band 5 Landsat prints (Fig. 22).

We recommend that densiometer studies be made of the Landsat coverage in Georgia and tonal signatures be defined in terms of geological units. Such study might then be followed by a "georeflectance" map in which areas of anomalous tonal pattern were examined on the ground to discover the cause for the anomalous reflectance. This might reveal geological differences not recognized during the mapping program. In states not recently mapped geologically, this procedure should help hasten the work by allowing

geological contacts to be taken from the imagery with a minimum of ground checking.

4. Use of aerial photography

Two photographic missions were flown using color infrared film, one in February and the other in April. A third mission was scheduled for fall, but because of cloud cover and scheduling conflicts, it was completed too late to be of use in the present study. We found the CIR coverage to be of great value in distinguishing vegetation types and recognizing plant stress. As a consequence, we recommend a regular schedule of this photography over an area undergoing investigation, spaced so as to include early spring greening of deciduous trees, summer foliage, the leaf abscission interval of fall, and mid-winter conditions of dormancy. Intermediate spring flights to detect more subtle phases of greening may be worthwhile in some areas. In monitoring plant stress, thermal infrared coverage is highly desirable.

IV. GEOBOTANICAL STUDIES

A. Geobotanical Relationships

The link between plant species and the presence of water or minerals was recorded by ancient writers. The Roman architect-engineer Vitruvius (1st century BC) pointed out plant indicators of groundwater, as also did his contemporary, the poet Virgil. Lucius Columella was a Roman writer on agriculture who lived during the 1st century AD. He wrote extensively on farm crops and recognized the control that soil minerals had on certain plants. Pausanias, a native of Lydia and 2nd century AD traveler in Greece and the eastern Mediterranean, gave accurate descriptions of the land and commented on the relation of plants and soil types.

Chikishev (1965), in the "Preface to the American Edition" of Plant indicators of soils, rocks, and subsurface water, lists many botanists of the 18th, 19th, and early 20th centuries who recognized geobotanical occurrences. Helen Cannon (1960) states that plants had been used as indicators of economic mineral deposits as early as 1828, but it was in 1937 that P. Dorn in Germany recommended a systemmatic prospecting program. The use of trace element analysis in plant tissue was described by the Russian S.M. Tkalich in 1938, and by 1945 geobotanical research units were a part of many field geological expeditions.

During the period between 1938 and 1948 the value of plant indicators in the search for metals was demonstrated by the successes of Scandanavian geologists in locating deposits of vanadium, tungsten, nickel, copper, and chromite (Cannon, 1960).

Geochemistry as an exploration tool in the search for minerals and hydrocarbons was much touted during the decade of the 1960's. By 1960 the U.S. and Canadian Geological Surveys had established geochemical prospecting units and a number of service companies and individual consultants were prepared to conduct projects for industry. Successes, especially in locating copper, nickel, and uranium deposits, encouraged the proliferation of geochemical surveys. The role of plants in concentrating trace elements was an important feature of many projects.

The early promise of geochemical prospecting has not been realized, and except for a select group of ores, few investigations are presently being launched. Poorly planned and misapplied efforts have fostered a reputation for failure, particularly among mining and petroleum companies. It is unfortunate that the concept was overextended because clearly there is a

place for geochemical exploration in the overall search for economic mineral deposits.

Plants have been used in prospecting primarily in three ways. These have involved the recognition and mapping of (1) indicator plants, whose nutritional or other physiological requirements are related to the availability of a specific mineral; (2) the concentration of certain materials in plant tissue; and (3) changes in plant morphology brought about by the presence of minerals.

1. Plant indicators of mineral occurrence

Plants that exhibit a preference for soils containing specific elements or minerals are called indicator plants. Only recently have such plant species been systematically evaluated. Where the plants always indicate the presence of a certain material, they are termed "universal indicators"; and if they act as indicators only within a limited area, they are called "local indicators".

Lists of indicator plants have been published by various workers, the most comprehensive being those by Brooks (1972), Cannon (1960), and Carlisle and Cleveland (1958). A compilation was made by Rommel *et al*. (1968) as NASA Special Report 5056.

No specific indicator plants were identified during our investigations. We concluded that if any were to be found within one of our prospect areas, they would occur in relation to the Gladesville Norite intrusion. Careful observation failed to reveal any distinctive species.

In addition to indicator plants, the concentration of certain metals may be recognized because they have a toxic effect on some vegetation, resulting in physiological and morphological changes. In sufficient concentration, copper, nickel, and zinc, all of which are present in the Gladesville Norite area, are known to produce such effects (Brooks, 1972). However,

none of the reported effects could be recognized in the Gladesville prospect, leading to the conclusion that the metals do not occur in sufficient abundance to be significant. Plant stress due to water deprivation can be recognized, and was a factor in identifying potential sinkhole areas, as described in the section relating to these investigations.

2. Geological factors in plant distribution

Edaphic control is most effective where rocks of contrasting type occur in a uniform, semiarid, plateau or subalpine environment. For example, the distribution of many plant species in the White Mountains of eastern California is controlled to varying degree by the underlying rock type (Marchand, 1973). The geology is a complex mixture of sedimentary, igneous, and metamorphic rocks. The oldest formations are slightly metamorphosed late Precambrian sediments which grade upward into a succession of Cambrian sedimentary rocks including sandstones, shales, limestones, and dolomites. The sequence was intruded by Mesozoic quartz monzonite, and following an Early Tertiary erosion interval, basalt was extruded prior to Late Tertiary uplift of the range.

The White Mountains lie in the rain shadow of the Sierra Nevada and are characterized by a cold, dry climate. Soils are poorly developed lithosols having a general $A_{11}/A_{12}/C/R$ profile. Color, sturctural, or textural B-horizons are rare, and caliche crusts are found on all lithologic types, being especially abundant on dolomite and limestone soils.

In the White Mountain study only 8 of 72 species showed complete independence of substrate affinity. The most pronounced geobotanical control recognized in the White Mountains, as well as in other study areas, including our own investigations, is between carbonate and non-carbonate

substrates. Three White Mountain species (Marchand, 1973, Table 2) are restricted to carbonate areas, but make no distinction between dolomite [$CaMg(CO_3)_2$] or limestone [$CaCO_3$]. Eight species are entirely absent from carbonate areas and many others are rare; however, there is often no special preference for variations among the non-carbonate substrate.

Where preferences can be noted in non-carbonate areas, they generally reflect differences between volcanics (such as lava flows), quartzites, and rocks of mixed composition. These have been the observations of various investigators (e.g., Wright and Mooney, 1965; Mooney, 1968; Marchand, 1973). We have noted similar occurrences in Georgia and Alabama. Most notable geological control of vegetation here also is in areas of carbonate rock, with quartzite outcrop belts distinctive to a somewhat lesser extent.

Depth of soil development is an important factor in moderating the influence of the bedrock composition. For example, in the Albany area, which is underlain by the Ocala Limestone, a residual red clay soil up to 7 m thick is widely developed, and bare rock or an immature soil profile is less common than in limestone country of the southern Appalachian region. On the contrary, in the outcrop belt of the Demopolis Chalk in Alabama, where soil development is poor, wide expanses of the terrain have very sparse tree cover, of which cedar is dominant. The small isolated outliers of Ocala Limestone (U. Eocene) at Rich Hill in Crawford County, Georgia, appear to be slump blocks surrounded by Cretaceous sands and clays. There is almost no soil on the limestone, and redbud is the most abundant tree. The edge of the limestone is marked by well-developed oak-pine woodland.

Floras characteristic of a geological formation may be considered "indicator communities". While they will not in themselves indicate

mineralization, they may delineate outcrop belts within which certain types of minerals are likely to occur.

Russian investigators have been active in large-scale integrated studies resulting in combined "nature" maps, which include geobotanical and "landscape" maps (Krauklis and Medvedev, 1970). The mapping involves establishment of "type plots" by geobotanists, ecologists, and topographers. The Russian scientists treat an elementary geosystem as a physicogeographical facies and consider that this facies mapping is a means of "systematizing the interrelations between components of elementary geosystems" (Krauklis and Medvedev, 1970, p.2). Unfortunately, either the language of the original papers or that of the translations (or both) are so burdened with recondite and undefined terms, it is difficult to evaluate the success of the method.

B. Remote Sensing of Vegetation

1. Principles

The remote sensing of vegetation is based on detection of reflected or emitted energy from the plant, especially the leaves. There are several conditions and activities of the plant, or its environment, which influence the quality of the reflection or emission spectrum that can be obtained from it. Healthy vegetation contains chlorophyll as well as other associated pigments which preferentially absorb in the blue and red wavelengths of visible light while being very efficient reflectors of energy beyond red. Stressed, diseased, or dead leaves exhibit marked changes in absorption and reflection capabilities, which can be detected by thermal (IR) sensors at lower levels of deviation from the normal than can be detected by direct visual inspection. Normal seasonal changes in plant growth and development also heighten the contrast between species of plants which undergo such

activities as bud-break, leaf expansion, or leaf abscission at slightly different times. Deciduous and evergreen forests give remarkably different signatures as the "Green Wave" advances to the north each spring, or the "Brown Wave" advances southward in the autumn. Photography within the visible range, IR photography from high and low-altitude aircraft, manned satellite (Skylab), and Landsat IR imagery are all useful for rapidly distinguishing hardwoods, softwoods, mixed forests, and many agricultural crops.

Some of the differences seen in ground cover vegetation are due to the environmental variations to which the vegetation is exposed. This is immediately obvious to even an inexperienced observer when first viewing a false color IR print which displays bright red circles produced by vegetation under a center-pivot irrigation system. The presence of abundant soil moisture is indirectly observed by the high IR reflectivity of the crop plant leaves. A marked change in forest vegetation may indicate a change of species due to a different soil in the adjacent area. Such a change over a very short distance could also be caused by altitude, solar exposure (north-facing or south-facing slopes), application of fertilizer, presence of disease, or a variety of environmental factors other than the underlying geology. The complexity of natural vegetation with irregular patterns and intermingled species, as opposed to the monoculture of agricultural crops, requires more field work to establish ground truth, and presents more difficulties of interpretation and therefore a lower level of reliability than does crop identification.

2. Techniques

At present, Landsat imagery can be used to classify reliably four categories of forest: hardwood, softwood, mixed hardwood-softwood, and

regeneration (Kan and Dillman, 1975). This can be accomplished by visually scanning the Landsat prints, especially the false color IR composits, where band 7 reports the differences in IR emission from the various types of vegetation, or vegetation under different conditions. Besides prints, the data can be handled directly from magnetic tapes, or enhanced through computer manipulation. Either way a known vegetation cover can be identified and its signature used to identify more of the same vegetation. With agricultural crops, generally the terrain is more uniform, the phenology better known, and the vegetation is a single well-known species of uniform age. This permits crop identification and acreage estimates with above 95% accuracy (Dietrich et al., 1975).

We found that the Gladesville, Andersonville, and Pine Mountain areas were of such complex terrain and vegetation patterns that the Landsat imagery was of little use compared with the lower altitude photography of Skylab and aircraft. IR photography, from both high altitude (U-2) flights and lower altitude flights gave the resolution necessary to develop vegetation maps for these areas. After establishing the identity of vegetation types in the field, it was possible to delineate these vegetation zones directly from the photography with the aid of a stereoscopic viewer. These vegetation zones were traced and subsequently transferred to 7.5-minute topographic maps of each area. The plant community nomenclature used in this report is that of Plummer (1974). The resulting vegetation maps were compared with vegetation maps made available by the Georgia Department of Natural Resources, and with geological maps of each area.

V. GLADESVILLE NORITE

A. Introduction

Plutonic rocks of the basalt-gabbro clan are characteristically

composed of dark-colored silicates, with dark calcic plagioclase (labradorite) and pyroxene minerals predominating. Concentrations of chromite, nickel, copper, zinc, vanadium, and the platinum group of elements are associated with gabbroic intrusions throughout the world. Notable ore bodies include the Sudbury, Ontario, norite-micropegmatite and a similar intrusive at Petramo, Finland, from which nickel and copper sulfides are mined. Norite is a mineralogic variety of gabbro in which the pyroxene crystallized in the orthorhombic system, often as the variety hypersthene of the orthopyroxene group.

The norite is intrusive into hornblende gneiss of the Piedmont geological province, and is itself cut by granite pegmatites which are largely restricted to the norite area and appear to be a late residual or derivative product of the norite. Still later intrusion is represented by diabase dikes which transect both the norite and the hornblende gneiss.

1. Location and area

The Gladesville Norite outcrops in southwestern Jasper County, Georgia. It is located between Forsyth and Monticello (Fig. 1 and 2) and lies within the Oconee National Forest. The outcrop area is oriented northeast-southwest and is about 13 km long. It averages about 1.5 km wide except at the northeastern end where the width is about 5 km. For more than half its length, beginning at the southwestern end about 3 km southwest of Gladesville, State Highway 83 is on the outcrop belt and runs within about 300 m of its northern edge.

2. Objective

The Gladesville Norite is the largest known basic intrusive body in Georgia (Carpenter and Highes, 1970). It was selected for study because of its relatively large outcrop area and because the geology had

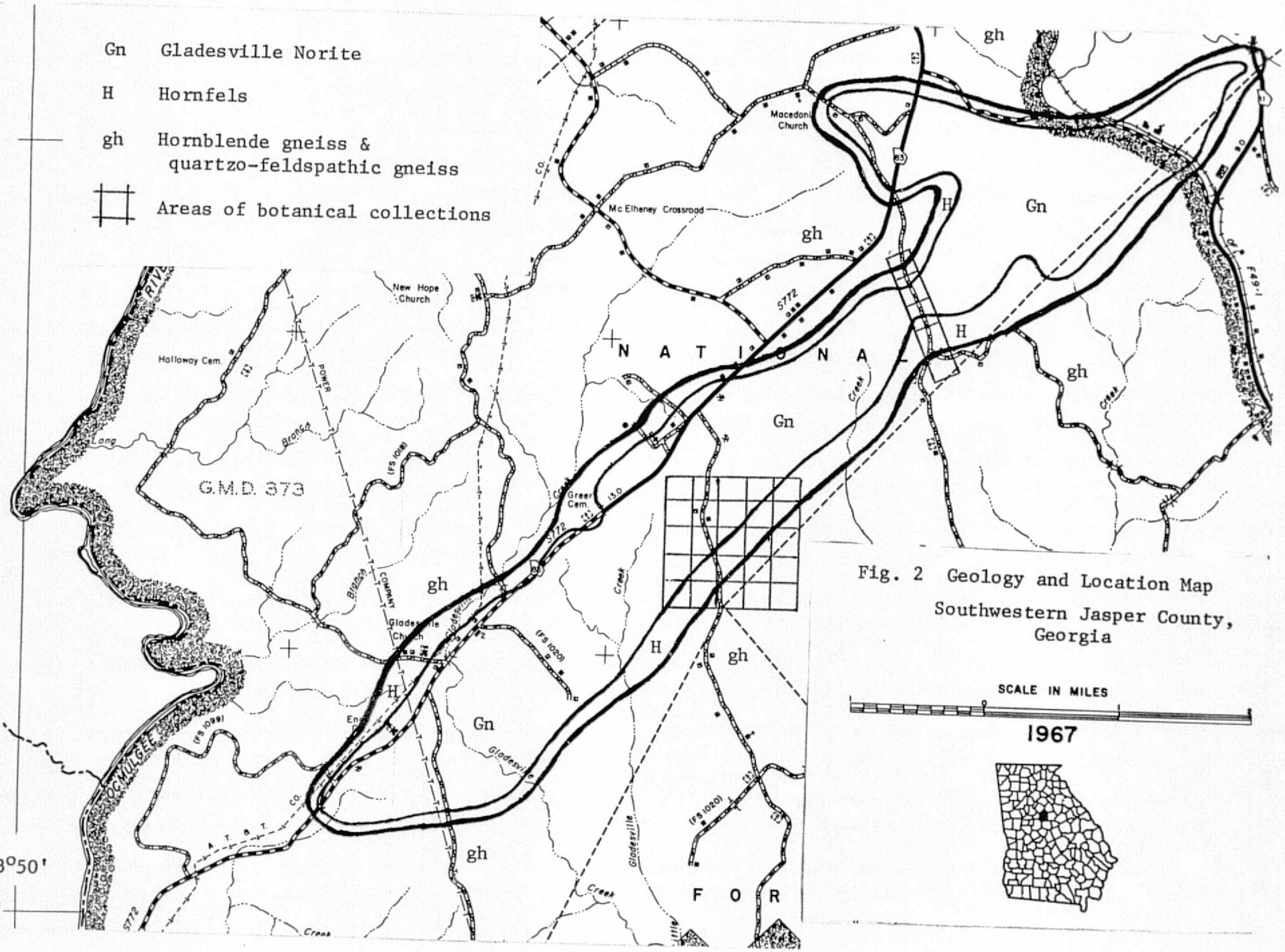

Fig. 2 Geology and Location Map
Southwestern Jasper County, Georgia

been described in some detail (Matthews, 1967; Salotti and Matthews, 1969; Prather, 1971). It was felt that if mineralization commonly associated with norite bodies, especially copper, zinc, and nickel, has an effect on vegetation in a region of temperate climate and deep soil development, the Gladesville intrusion would be a likely place to find evidence for such effect.

B. Geology

1. Regional geology

The region is underlain by hornblende gneiss (50-70%) interlayered with quartzo-feldspathic gneiss and migmatite (Georgia Geological Survey, 1976; Matthews, 1967). The rocks are dominantly metasediments and rarely show evidence of having been derived from igneous origins. Metamorphism has reached the kyanite-almandite-muscovite phase. Foliation in the gneiss has a northeast regional strike and generally vertical dip.

After regional metamorphism, the rocks were intruded by the Gladesville Norite which, by contact metamorphism, left a boundary zone of pyroxene hornfels 60 to 365 m wide. Numerous mafic dikes and granite pegmatites intrude the norite, and three northwest-trending diabase dikes cut across all of the other crystalline rocks.

2. Gneisses

Hornblende gneiss composes 50-70% of the metamorphic rocks. In hand specimen its mineralogy uniformly appears to be hornblende and white plagioclase, with quartz rare. Modal analyses by Matthews (1967) show:

Hornblende	61-65%
Plagioclase (andesine)	39-30%

Epidote	0-4%
Magnetite	0-1%

The rock is weathered and forms an orange or red saprolite, the Davidson clay loam. Grains of feldspar and quartz are scattered through the soil, and since the hornblende gneiss is the most resistant to weathering of the rocks occurring in the area, it is found widely as float. Often these fragments are scattered through the soil overlying other rock types, such as the more felsic gneiss, thus creating the appearance that the hornblende gneiss is more abundant than is actually the case.

Quartzo-feldspathic gneiss is interlayered with the hornblende gneiss, with thickness of individual layers varying from 15 cm to 75 m and with an average thickness of 30 to 90 cm. The rock is composed chiefly of plagioclase (An_{20-25}), microcline, and quartz, with accessory biotite, sericite, garnet, tourmaline, and zircon (Prather, 1971).

It is suggested that the original rocks were calcareous shales in the case of the hornblende gneiss and that the original sediment of the quartzo-feldspathic gneiss was an arkose or similar sandstone. There are some layers of hornblende gneiss which were probably derived from ancient basic igneous intrusives.

3. Norite

The norite complex outcrops over a 23 km^2 area. On fresh surfaces it is medium to dark gray in color, with mineral grains commonly 1 to 3 mm in diameter. It becomes more fine-grained near the margin of the intrusion and assumes a diabase-type texture. A rhythmic layering has been described by Matthews (1967), caused by variations in mineral composition. For example, olivine will be evenly distributed throughout a layer, then the

olivine will abruptly disappear with only plagioclase and pyroxenes present. The olivine-rich layers are commonly 3 to 5 cm in thickness, while the intervening layers are 15 to 20 cm thick.

A modal analysis of the norite is (Matthews, 1967):

	Plagioclase (An_{65-70})	50%
	Clinopyroxene	19
	Orthopyroxene	24
	Hornblende	7
Also present are:	Olivine	0 to 13%
	Actinolite	0 to 15
	Serpentine	trace
	Carbonate	trace

The norite is readily affected by chemical weathering and has no significant topographic expression. The resulting saprolite ranges from gray or olive colored in fresh exposures to yellow and brown in older exposures. The dominant soil type is Iredell loam. It is very plastic and sticky when wet. Float is not common and does not develop the distinctive weathering rind that is always characteristic of float from the hornblende gneiss.

4. Contact metamorphism

Thermal metamorphism is effective for a distance of about 300 m surrounding the norite intrusion. Regional metamorphism of middle amphibolite grade had been reached prior to the intrusion, so the subsequent thermal effect of the norite mass is not sharply defined.

An aureole of pyroxene and hornblende hornfels is the chief evidence for intrusion. This contact metamorphism plus the nature of the norite, including euhedral form of crystals and lack of cataclastic textures, indicates the molten and relatively high-temperature condition of the

norite at the time of emplacement. There is general decrease in grain size and increase in the amount of hypersthene near the contact.

5. Dike rocks

Three types of dikes are noted in the area. Numerous mafic dikes cut the norite but do not cut granite pegmatites which are largely confined to the norite area. A younger set of diabase dikes cut across all other rocks.

The mafic dikes rarely extend into the metamorphic series and certainly are later than the norite which sometimes shows contact alteration. The dikes have no preferred orientation and may be straight or sinuous. Their thickness ranges from no more than 2 cm to as much as 3 m. Most commonly, the composition is plagioclase and brown hornblende derived from hypersthene.

The granite pegmatites range from a few centimeters to more than 30 m wide and attain lengths up to 100 m. Normally, exposures of these dikes are rare, but several of the larger masses are exposed in quarries, both active and abandoned. The pegmatites are essentially graphic granite, composed of quartz and microcline.

Three diabase dikes are present in the area. They strike northwest and are vertically oriented tabular bodies. The largest cuts across the northern end of the norite mass. It is 25 to 30 m wide and at least 16 km long. The composition of these dikes is predominantly plagioclase and augite. Presumably the diabase dikes are related to similar intrusions in eastern North America that have been dated as Late Triassic to Middle Jurassic in age. This establishes a minimum age for the norite, but there is no other check on the age and we are not aware of any radiometric age determinations from rocks in the area.

6. Geophysical and geochemical surveys

Results of gravity, magnetic, and geochemical surveys (Fig. 3-5) were reported by Carpenter and Hughes (1970). There is a steep gravity gradient with lowest values occurring in the northwest and increasing towards the southeast. There is a variation of about 45 milligals over a distance of 18 km. The inference from these data is that basic intrusives are extensive in the subsurface southeast of the Gladesville Norite and the exposed portion may represent only a stock extending from a larger buried batholith.

This interpretation is consistent with the magnetics data. The norite and contact zone contain significant quantities of magnetic minerals and pronounced positive anomalies are found here.

Stream sediment was analyzed by Carpenter and Hughes (1970) from 37 localities in the vicinity of the Gladesville Norite. Background values for nickel ranged from 1[illegible] to 208 ppm (Fig. 3), and samples with more than 210 ppm were judged to be anomalous. More than half of the area was found to exceed this value, and a small area near the northeastern end of the outcrop area exceeded 300 ppm.

One area containing 3 samples showed an anomalously high proportion of copper (Fig. 4). These samples, from the northeastern area, contained more than 215 ppm, where 97 to 198 ppm was the background range.

Background for zinc was calculated as 140-239 ppm. Two areas exceeding 250 ppm were found, one located about 3 km south of the outcrop belt, the other in the same area as the high nickel and copper values (Fig. 5).

C. Botanical Survey

Most of this area is forested because the steep terrain does not make it acceptable to agriculture. Some logging is being done, and much

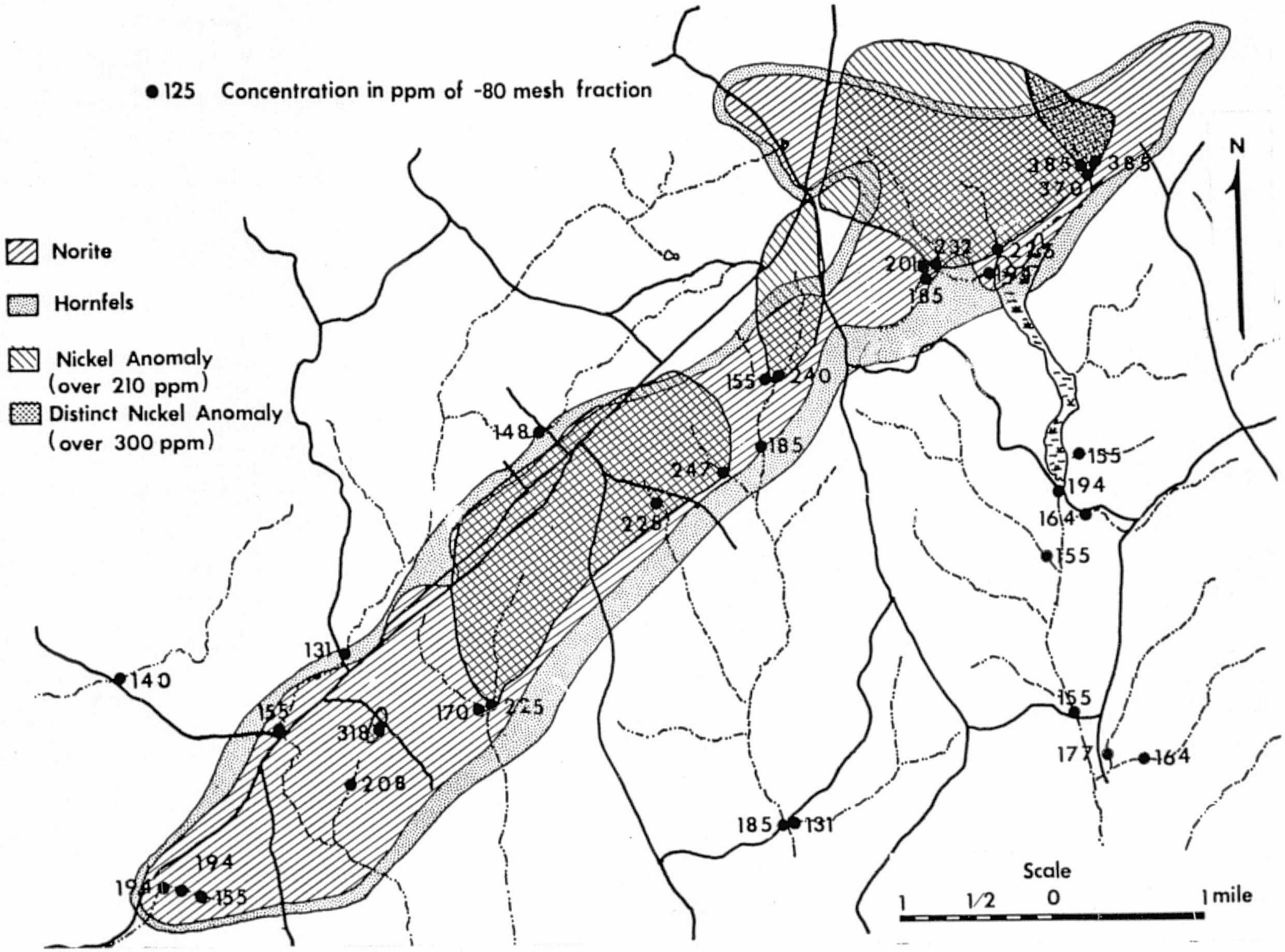

Fig. 3. Nickel Content of Stream Sediments in Southern Jasper County, Georgia (Carpenter and Hughes, 1970)

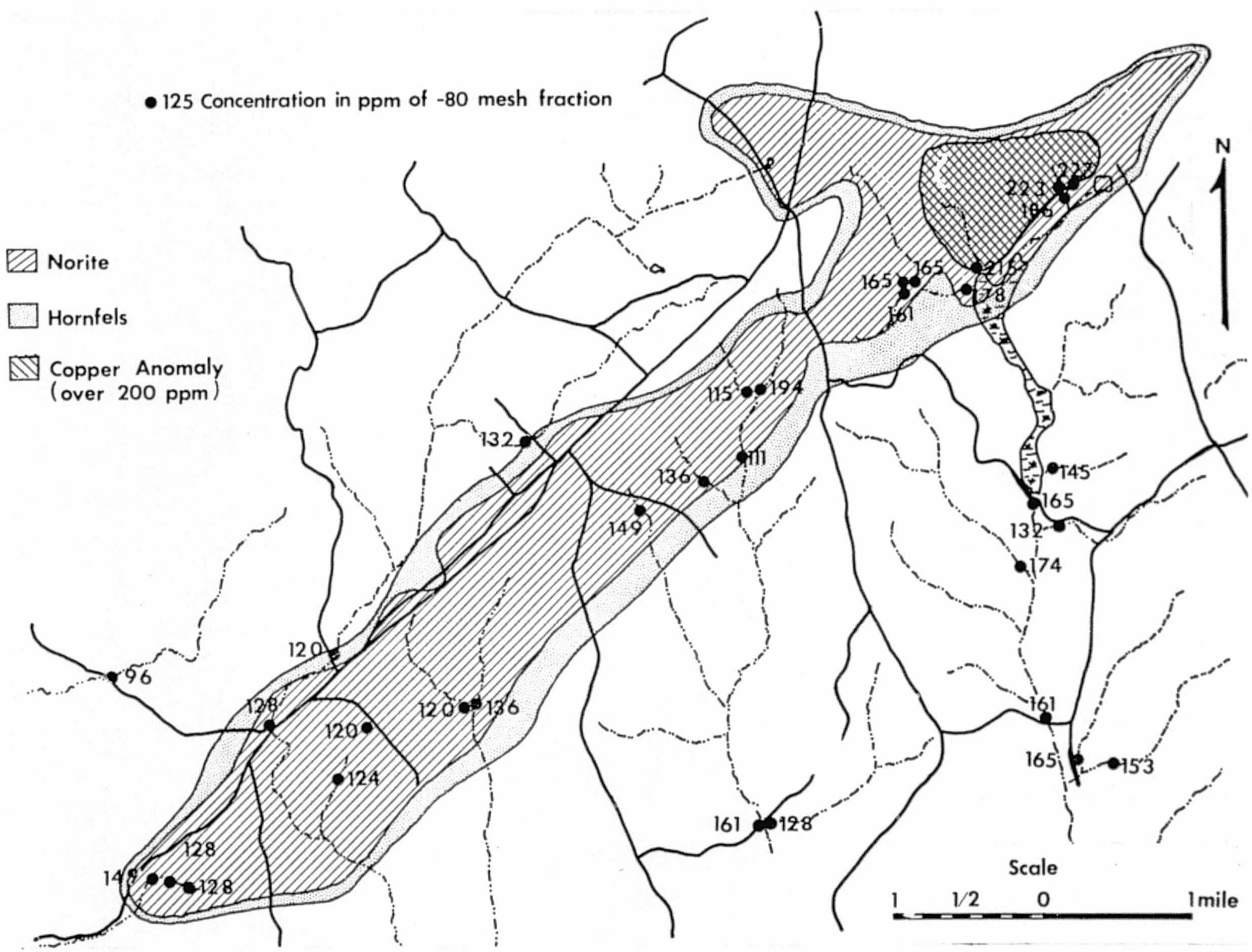

Fig. 4. Copper Content of Stream Sediments in Southern Jasper County, Georgia (Carpenter and Hughes, 1970)

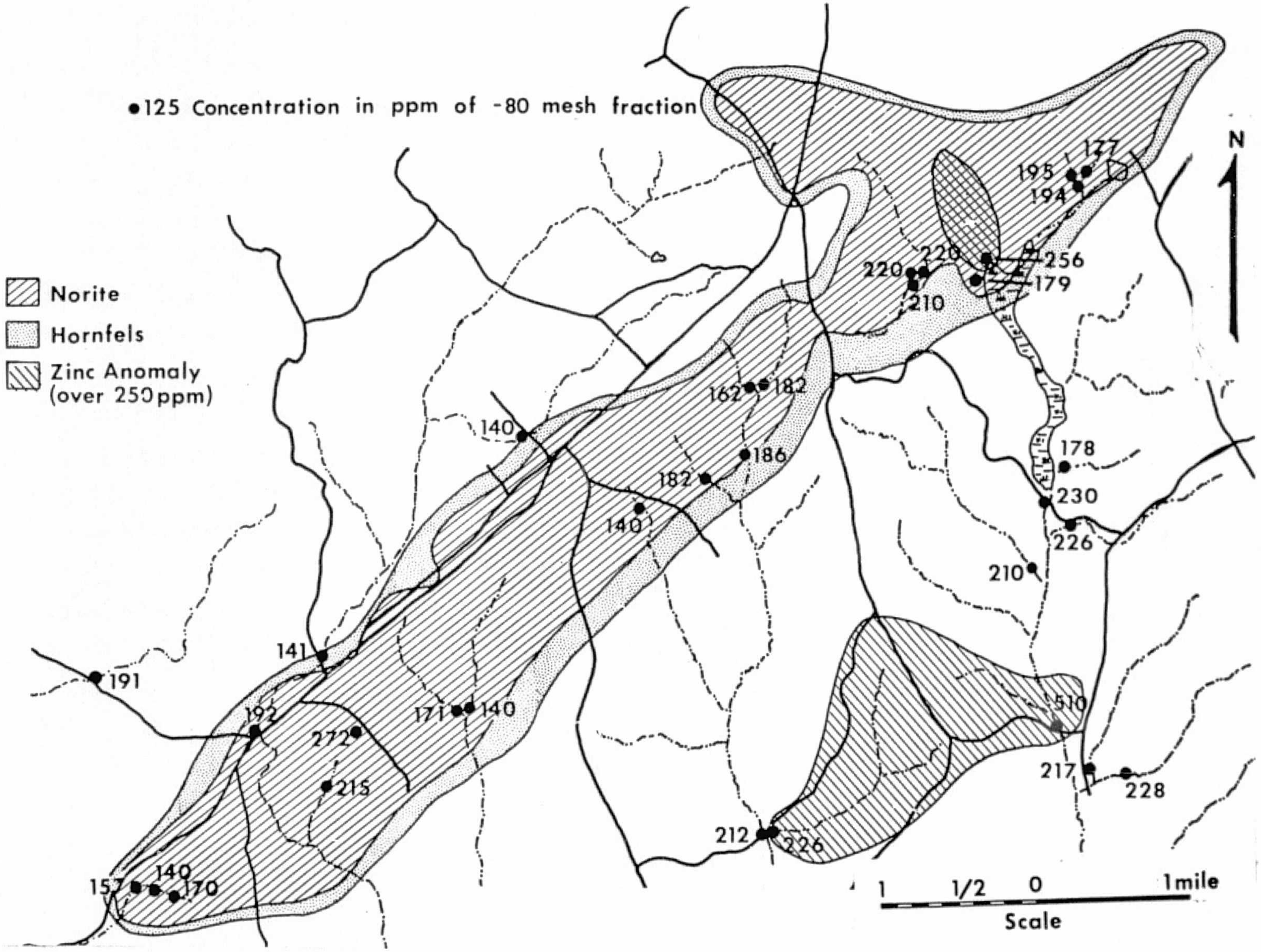

Fig. 5. Zinc Content of Stream Sediments in Southern Jasper County, Georgia (Carpenter and Hughes, 1970)

has been done in the past. There are portions which are planted in loblolly pine (Pinus taeda), however, most of the steeper terrain is a natural regrowth of mixed hardwoods in the lower elevations and along streams, with mixed hardwoods and softwoods on the higher ground. Hickory species (Carya tomentosa and C. glabra) are frequent on the steep north-facing slopes. This vegetation is similar to that found throughout the Southeastern States, having been described in many independent studies (Quaterman and Keever, 1962). The initial study area was selected where there was a minimum of disturbance to the vegetation and where the area was known to include vegetation over the norite intrusion, adjacent vegetation clearly not over the norite, and vegetation within the transition zone. A test site of one square mile was selected and the vegetation within this area was investigated. Notes were made descriptive of the vegetation, plants collected and identified and a vegetation map was completed for the area. From aerial photographs it was possible to extend this vegetation map to include most of the known outline of the norite outcrop. No attempt was made to identify any agricultural crops being grown within the study area, also plantings of pine were ignored in field work since these would not be natural plant indicators. If left to time and natural forces most of this agricultural land and pine plantings would, through succession, become mixed pine-hardwood forests like the adjacent ridges and valleys.

D. Results

The pattern of plant community distribution, and community composition on the norite outcrop was consistent with that of the communities adjacent to the intrusion and in the transition zone. Similarly, species composition did not alter for those communities which overlap the border of

the intrusion so that we conclude the differences in community composition and the placement of vegetation are not a result of the norite body directly, rather they are influenced primarily by relief. Maple (Acer) is consistently found in the bottomlands along streams, with sweetgum (Liquidambar) growing in the low and intermediate elevations of the drainage pattern. The distribution of pine (Pinus) shows a consistent preference for the ridges and higher elevations. The oaks (Quercus) and hickories (Carya) cross the geological transition zone with a pattern indicating a preference for the well-drained steeper slopes, with hickory predominant on the north-facing slopes. Dogwood (Cornus) is limited to the highest elevations under the shade of pine and oak. The drainage pattern, shown by "L" or lowland hardwoods, reveal streams flowing away from the norite along both the northern and southern borders, while most of the intrusion is covered with high level ground, as indicated by the presence of pines (H) and deciduous hardwoods (E) or agricultural land (Fig. 6 and 7).

The symbols used are those of the Georgia Resource Assessment Program (Plummer, 1974) with the addition of "Q" to represent quarry in this map. The symbols are as follows:

A	= agricultural land
CUT	= lumbering, recent or in progress
E	= upland hardwoods, scattered pines
H	= pines, scattered hardwoods
L	= lowland hardwoods
Q	= quarry

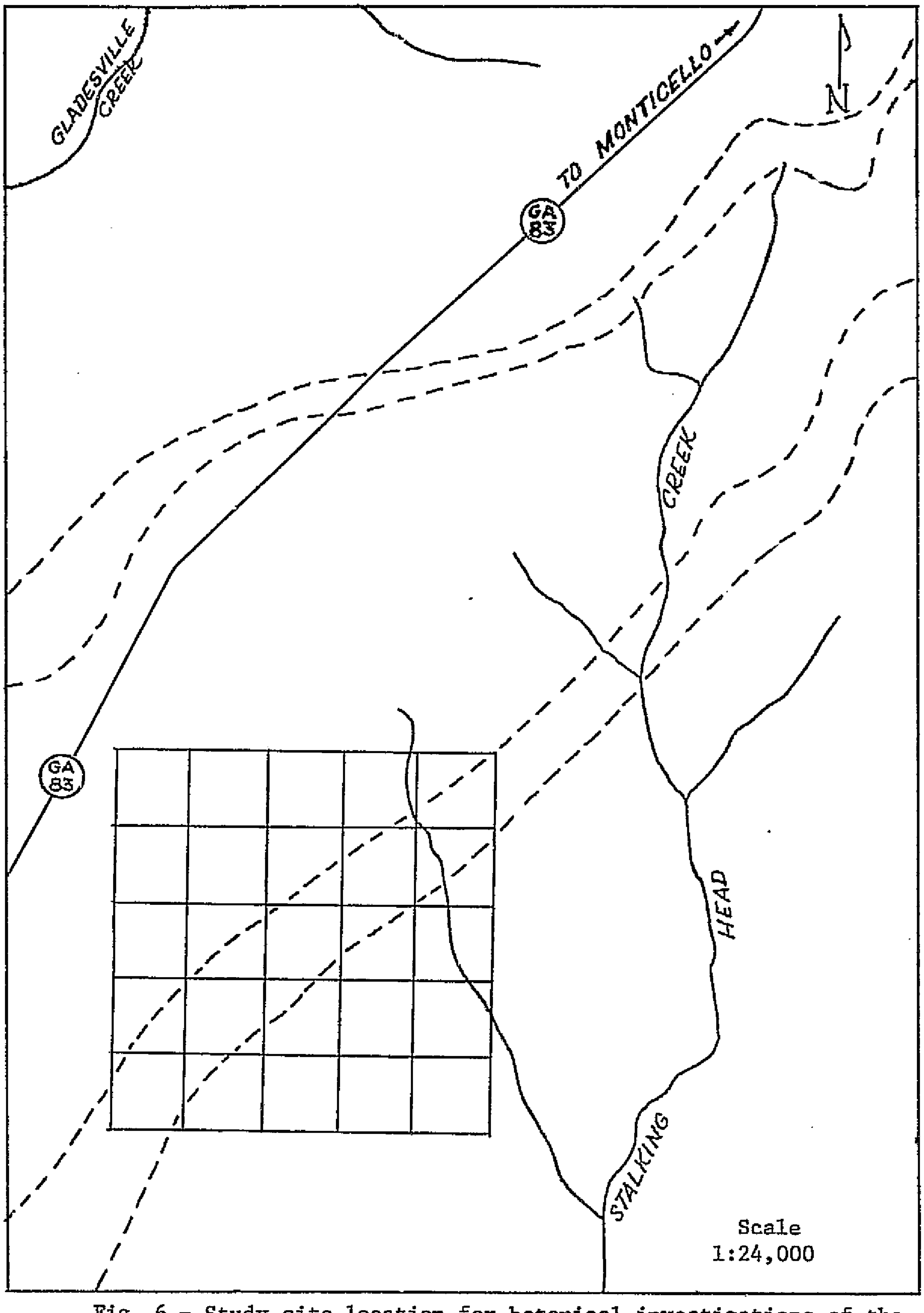

Fig. 6 - Study site location for botanical investigations of the Gladesville Norite.

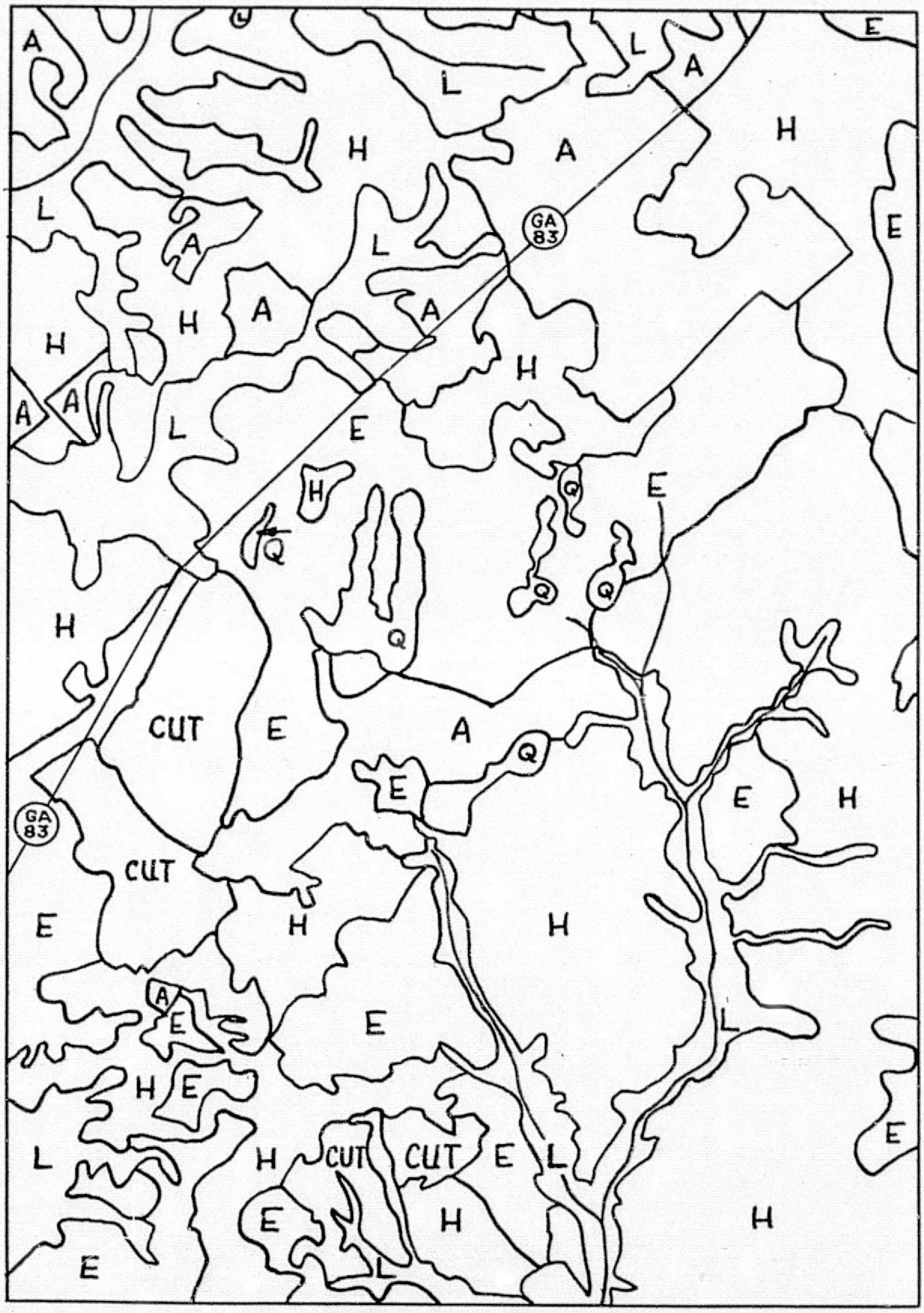

Fig. 7 - Vegetation map of Gladesville Norite and surrounding area.
Same coverage as shown in Fig. 6.

VI. PINE MOUNTAIN AREA

A. Introduction

The Pine Mountain area is of special interest because it brings rocks of widely differing age and lithologic types into juxtaposition along two or more large fault zones. There are three important fault traces within the area of investigation, two of which (Goat Rock and Bartletts Ferry faults) may be part of the same arched low-angle thrust. The major rock units involved are metamorphics of the Uchee Belt and the Wacoochie Complex of the Pine Mountain Belt. Diabase dikes of presumed Mesozoic age also occur in the area.

1. Location

The area of investigation (Fig. 8) is in Harris County, Georgia, and is bounded on the west by the Chattahocchee River, on the east by the 85°00' W Longitude line, and on the north and south by the 32°45' N and 32°35' N Latitude lines respectively. The area comprises the "Bartletts Ferry Dam" (Georgia-Alabama) and northern one-third of the "Smiths" (Alabama-Georgia) U.S. Geological Survey 7.5-minute topographic quadrangle maps.

2. Objectives

Two principal objectives could be realized in the Pine Mountain area: (1) examine the influence on vegetation of highly diverse lithologic types; and (2) observe the effects of intensive thrust faulting.

The lithology of the region includes a variety of metamorphic and intrusive igneous rocks. There is considerable range of chemical and mineral composition, from the nearly pure quartz sand origin of the Hollis Quartzite to the aluminous-graphitic content of the Manchester Schist, or the dense, fine-grained dolomite of the Chewacla Marble.

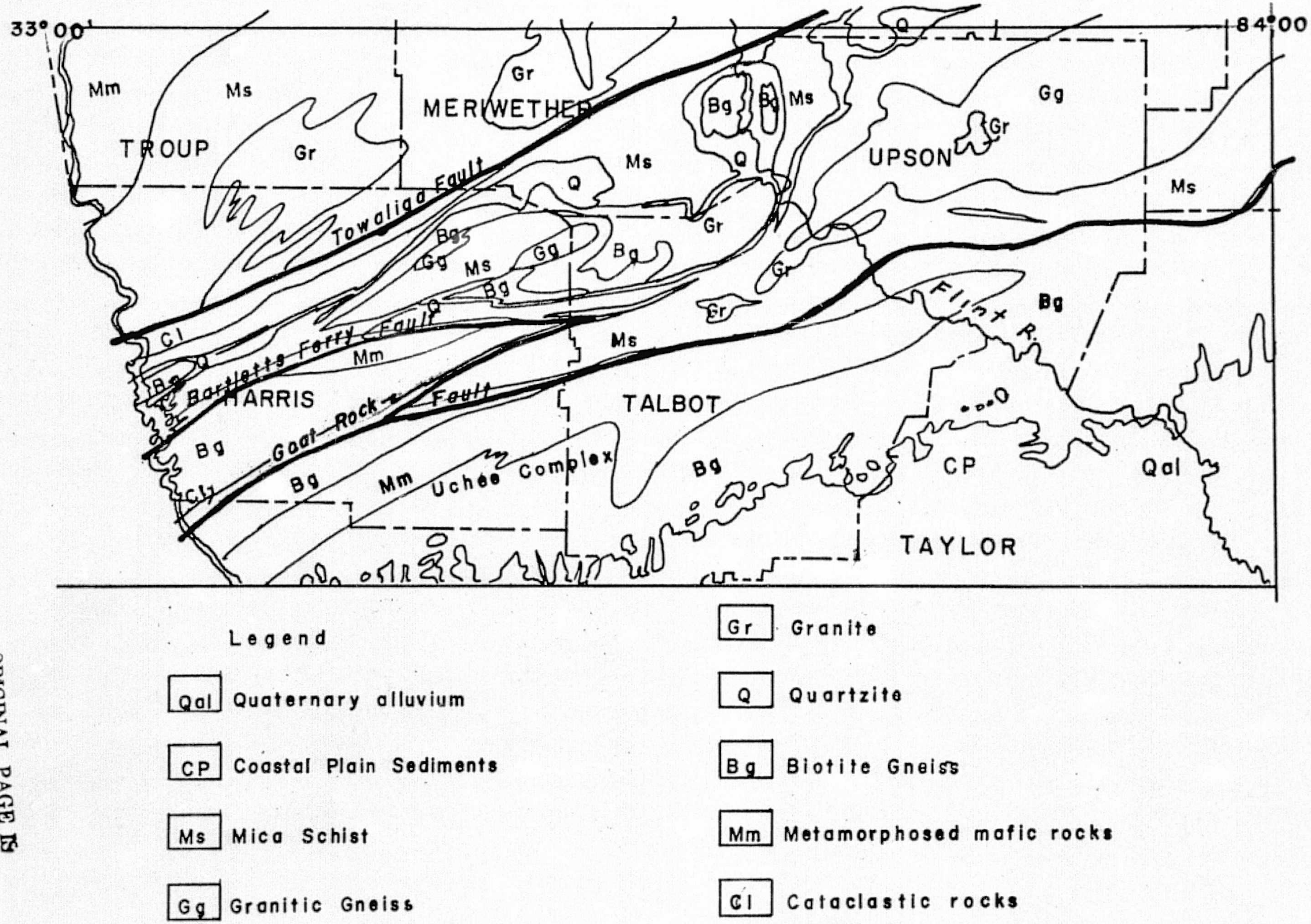

Fig. 8. Generalized Geology and Location Map of Pine Mountain Area

Faults are marked by intensely sheared cataclastic belts within which several grades of mylonite have developed. These range from dense black ultramylonite to blastomylonite containing porphyroblasts of feldspars up to 20 mm in diameter. Polyphase folding has further complicated the structural pattern.

The study area is clearly defined by boundary faults and although the internal structure is complex, any geologic control of vegetation patterns can undoubtedly be identified.

B. Geology

The southern end of the Piedmont geological province is a belt of crystalline rocks in Georgia and Alabama which lie between the cover of Coastal Plain sediments on the south and Paleozoic sedimentary and metasedimentary rocks to the northwest. Recent work in the area has resulted in new interpretations of the geological history and structural relationships. Some of the hypotheses are conflicting and there is still insufficient data to resolve them, but the implications of the work in progress are exciting, and whatever answers eventually emerge are certain to modify conventional concepts of the history of the southern Appalachians. The various problems are far too numerous and complex for adequate review here. However, we can say that an understanding of the geological relationships within and adjacent to the Pine Mountain area would go far toward resolving many regional problems.

Improvements in radiometric dating techniques and increase in the number of research centers in the Southeast with equipment for such investigations has encouraged field mapping in these structurally complex areas of metamorphic and igneous rocks. Relative ages for the larger units have been

established with reasonable confidence and local details are being investigated. Increase in data collection, however, has not resolved the fundamental question of the origin of the Brevard fault or even its subsurface configuration, and the structural history of the southern Piedmont is still highly controversial.

The Brevard fault zone separates the Blue Ridge geological province from the Piedmont province (Fig. 9). A Penrose conference was held in August 1974, under the sponsorship of the Geological Society of America, during which a group that included many workers now active in the region examined the Brevard zone from its southern end in Alabama to near Roanoke, Virginia (Hatcher, 1975). The investigators began in the Pine Mountain area where evidence for polyphase folding was examined. The group then crossed the Inner Piedmont belt to the Brevard zone, where R.D. Bentley and T.L. Neathery pointed out field evidence to support their interpretation (Bentley and Neathery, 1970) that the rocks swing around the end of the Inner Piedmont beneath the Coastal Plain and emerge either as the rocks within the Pine Mountain belt or as some of the rocks northwest of the Towaliga fault zone. Clarke (1952) had earlier suggested that the Brevard, Towaliga, Goat Rock, and Bartletts Ferry faults bound a meganappe that carried the rocks of higher metamorphic grade of the Inner Piedmont over the rocks of lower metamorphic grade of the Pine Mountain belt and Brevard zone. These and other ideas were examined during the field conference and although no consensus was forthcoming, some fundamental problems were stated to the general satisfaction of the group. This means that a substantial representation of the most knowledgeable workers are in agreement as to what answers are needed. Two other important results of the conference were (1) recognition of the continuity of deformational events from the Blue Ridge through the Brevard zone and

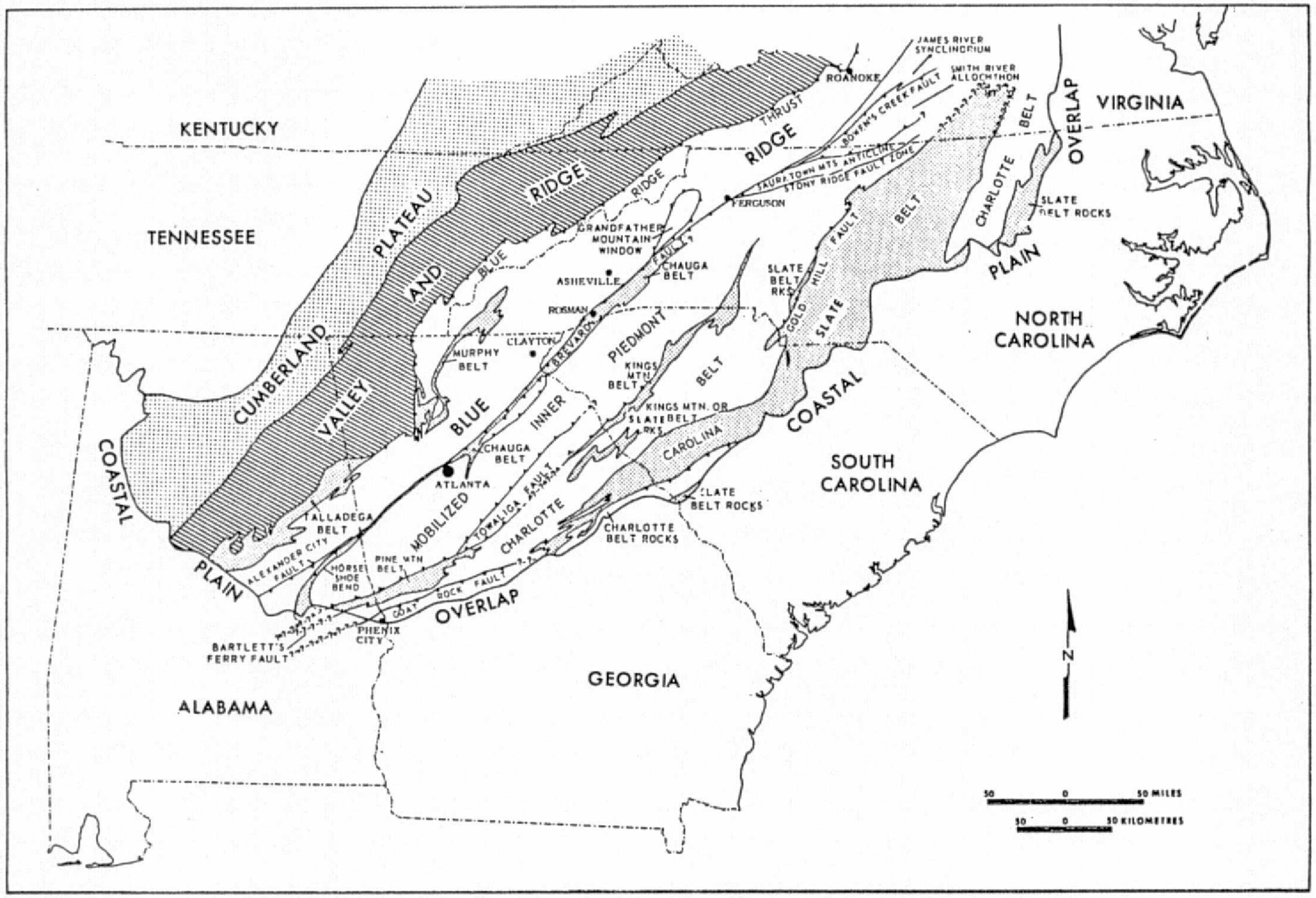

Fig. 9 Map of southern Appalachians showing principal geologic provinces and features discussed in report (From R. D. Hatcher, Jr.)

into the Piedmont and (2) a list of attributes of the Brevard zone:

1. It is a topographic lineament.
2. It is remarkably straight from Alabama to Virginia.
3. Rocks within the zone dip to the southeast.
4. There is no continuous stratigraphic unit that can be traced from one end to the other.
5. Cataclastic rocks are associated throughout its length.
6. It is a fundamental structure of the southern Appalachian orogen.
7. The zone changes character by splaying southwest of Horseshoe Bend, Alabama, and northeast of Ferguson, North Carolina.

1. Pine Mountain belt

The Pine Mountain belt is separated from the Inner Piedmont to the north by the Towaliga fault zone and from the Uchee belt to the south by the Bartletts Ferry-Goat Rock fault zone. The cataclastic belts of the fault zones are relatively wide (e.g., the Towaliga fault zone is 6 km wide) so that the Pine Mountain belt is reduced to a strip little more than 3 km wide at its western end. The belt widens to about 16 km in eastern Harris County and is 24 km wide at the longitude of Thomaston, Georgia.

The rocks are divided into two units: (1) the Wacoochee Complex and (2) the Pine Mountain Group. The exact nature of the contact between the units is uncertain; cataclastic rocks occur at most exposures, suggesting it may be a fault contact.

The Wacoochee Complex is the older of the two units in the Pine Mountain block. It includes: (1) the Woodland Gneiss, an augen gneiss characterized by potassium feldspar augens in a biotite-muscovite-quartz matrix (Hewett and Crickmay, 1937); (2) the Sparks Schist, a metasedimentary feldspathic

mica schist; and (3) the Cunningham Granite, an associated charnokitic granite which may intrude the other two units. Rocks of the Wacoochee Complex have been dated at about 1,000 m.y., based on U-Pb analysis of zircons and Rb-Sr whole rock isochrons (Steven Schamel, personal communication).

Pine Mountain Group. This group consists of metasediments, and because it is not intruded by granites as the Wacoochee Complex appears to be, the Pine Mountain Group is assumed to be younger. The stratigraphic sequence is not clearly demonstrated, but appears to be, from older to younger: Hollis Quartzite, Chewacla Marble, and Manchester Schist.

It has been suggested that there may be two quartzite units (Bentley and Neatherly, 1970): (1) a massive thick-bedded unit and (2) a thin-bedded unit. The massive unit appears to be older; the thin-bedded quartzite may be part of the Manchester Schist (Clarke, 1952). The quartzite beds are very pure and are composed almost entirely of quartz, with only minor amounts of feldspar, muscovite, or sulfides. Thickness may reach 335 m.

The Chewacla Marble is present only in Lee County, Alabama, where it is an irregularly occurring dolomite.

The Manchester Schist is an aluminous rock composed of biotite-muscovite-quartz and feldspar schists. In the lower part of the formation are variations including kyanite-muscovite, graphite, and biotite schists.

2. Towaliga fault zone

The Towaliga fault zone consists of cataclastic rocks, principally milonite, blastomilonite, milonite gneiss, and microbreccia. Slices of metasediments are present, including muscovite, quartz, sillimanite, and graphite schist; quartzite; and meta-arkose. These are probably sheared equivalents of the Pine Mountain Group.

3. Goat Rock fault zone

The Pine Mountain block is bounded on the south by an 8-km wide zone of cataclastic rock which is associated with two fault traces in Harris County: (1) Bartletts Ferry fault and (2) Goat Rock fault. These may be the eroded edges of a single arched nappe. The northern trace (Bartletts Ferry fault) divides and dies out near the Flint River in Georgia, while the Goat Rock trace extends into central Georgia where it may disappear beneath the Coastal Plain cover in Baldwin County. Side-look radar pictures made in the area for the Georgia Geological Survey show subsidiary fault traces, which had not previously been recognized, extending outward from the Bartletts Ferry fault.

C. Botanical Survey

A study site was selected which included relatively undisturbed vegetation growing over the major geological belts present in the Pine Mountain area. Botanical collections and observations were made throughout a north-south strip which was 2.6 km long and 1.6 km wide. The northern boundary was north of the mylonite zone and the southern boundary crossed over the southern edge of the Hollis Quartzite zone. The two zones are separated by a belt of Manchester Schist , as shown in Figure 10. After gaining familiarity with the area and its vegetation in the field, a vegetation map was prepared with the aid of stereoscopic examination of aerial IR photography. These were compared to the vegetation map of Harris County as prepared by the Georgia Department of Natural Resources. This Harris County map does not have the level of resolution necessary for our use, although it does provide a starting point for a system of vegetation classification. Our nomenclature follows that of Plummer (1974) as described in the "User's Guide for vegetation information" published by the Georgia Department for Natural Resources. We found it necessary to add one designation; that of north-facing

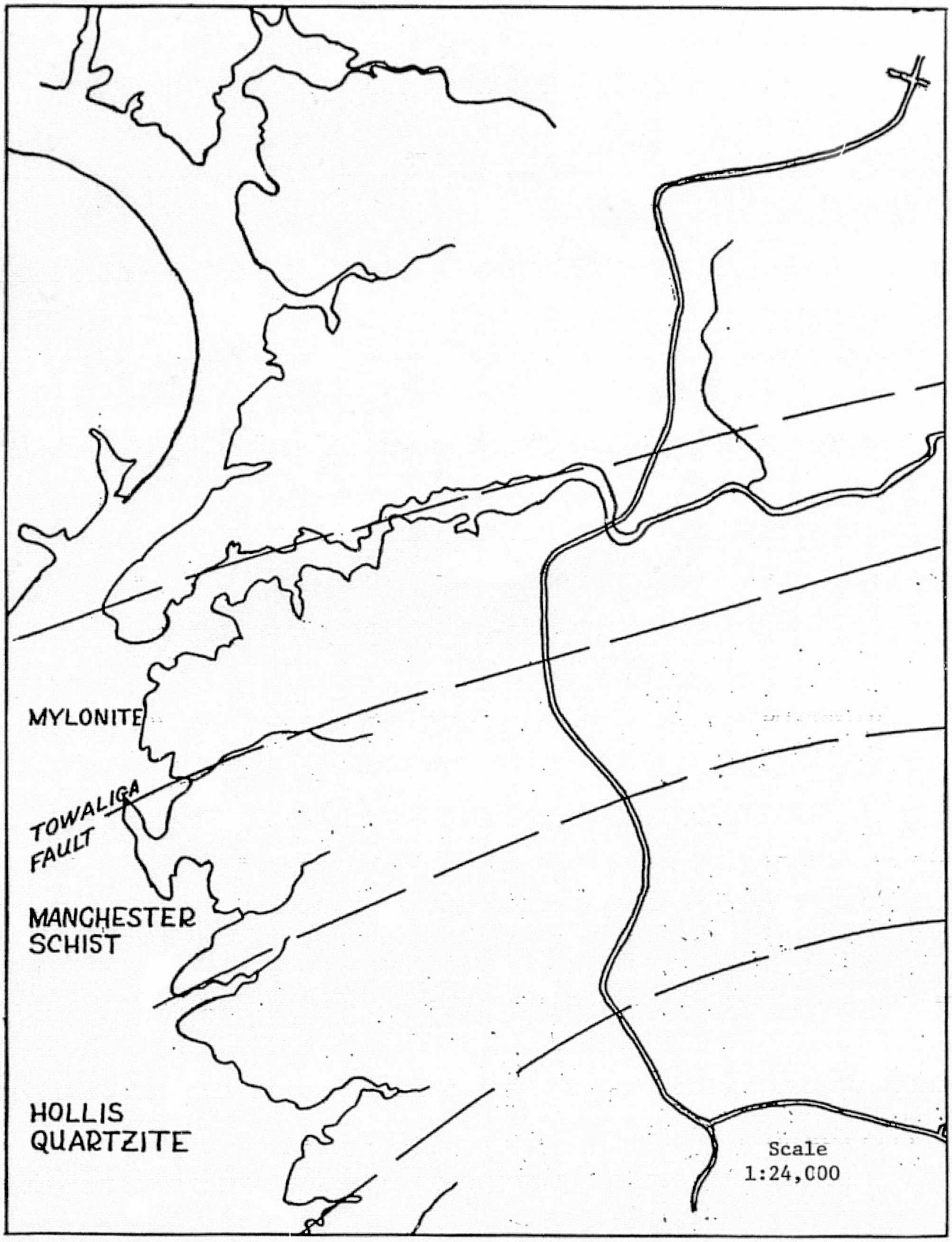

Fig. 10 - Study site location for botanical investigations in the Pine Mountain area.

slope (NFS). Steep north-facing slopes in and adjacent to the study area were of distinct vegetative character. These hillsides were predominantly (over 50%) hickory species (*Carya*) with some red oaks (*Quercus rubra*) present. This community is distinctive to these steep north-facing slopes. They are readily identified on the IR photography before bud break, i.e., on the film taken on the February 24, 1976 flight, as well as on the post-bud break film of April 9, 1976.

The several plant communities are readily distinguishable on the photographs of each date. The ridges and upper elevations (above 600 ft.) is a pine-hardwood community, with three species of pine: long-leaf pine (*Pinus palustris*), loblolly pine (*P. teada*), and short-leaf pine (*P. echinata*) being most abundant, mixed with three species of oak: white oak (*Quercus alba*), red oak (*Q. rubra*), and blackjack oak (*Q. marilandica*) less abundantly present. This community is designated as "V" on the vegetation map.

Along drainage systems a mixed lowland-hardwood community is present which typically comprises sweetgum (*Liquidambar styraciflua*), red maple (*Acer rubra*), tulip poplar (*Liriodendron tulipifera*) and water oak (*Quercus nigra*). The plant community along the Chatahoochee River and Mountain Oak Creek is categorized with the mixed lowland-hardwood forest, although its composition includes other hardwoods as: willow (*Salix nigra*), catalpa (*Catalpa speciosa*) and elm (*Ulmus alata*). This difference is not significant in this study, so for convenience the two communities are designated together on the vegetation map by the symbol "L".

D. Results

The lines of demarcation between the three geological belts were easily recognized in the field, so that each plant community could be assessed

while being aware of the geological substrate on which it was growing. The community boundaries are sharp, so there is little problem recognizing the changes between communities. It was found that vegetative zones crossed geological zones freely, maintaining their continuity or being terminated as a reflection of the topography and exposure, i.e., north or south-facing slopes. East and west-facing slopes are not recognized as supporting distinctive vegetation.

In each geological zone, and sometimes transversing one or two such zones, the ravines support a lowland mixed-hardwood community. This class is evident on the Hollis Quartzite, Manchester Schist, and the mylonite zones. The highest ridges in all three zones support a continuous pine-hardwood community, with some of the lower elevation ridges being distinguished as an upland hardwood-pine community, where the hardwoods become more abundant than the pine. These two communities are very similar in species composition, differing only in a change in relative abundance of pines to hardwoods. The symbol "E" is used to identify this community. This upland hardwood-pine community is developed on all three geological zones independently.

North-facing slopes with dry conditions, i.e., above the lowland hardwood community in the drainage basins, are covered with the predominantly hickory community. These, too, are to be found on each of the geological belts in the study zone. North-facing slopes are marked "NFS".

Working from the aerial IR photography, the vegetation map was extended beyond the designated boundaries of the study site. Throughout the entire mapped area these same relationships were observed between elevation, relief, and exposure with regard to the plant community developed under those conditions.

A map designating the 600 ft. elevation contour is presented to compare with the boundary between the lowland hardwood community and the upland pine-hardwood community (Fig. 11 and 12). The transition between the two communities is sudden and occurs close to the 600-foot elevation in most of this region. Below this line is the lowland community, and above it is the upland vegetation.

Examination of the Skylab CIR photographic prints of this area for January 22, 1974 shows color density differences which correspond to the overall vegetation distribution. This photograph (65 cm square) has a scale of 1:250,000. The darkest blue indicates the highest elevations, which corresponds to the upland pine-hardwood community covering it. The vegetation in the lowest elevation registers the lightest blue, coinciding with the bottoms of the drainage pattern, and includes those areas known to be the steep north-facing slopes. This gives a strong color contrast between the ridgeline and the adjacent north-facing slope whenever this grade is steep enough to influence the vegetation development to be the hickory stand which predictably is found under these conditions. The limits of resolution on this photograph do not permit recognition of the north-facing slopes separate from the lowland hardwoods. Extrapolating this data to the interpretation of the adjacent Pine Mountain range on this photo, we can predict the distribution of the lowland communities throughout its westerly extension from the study area. The IR photography is recording an exaggeration of the topography of the region by reporting differences in the IR emissions from vegetation of different species which were in distinctly different stages of development on the date of the overflight.

Similarly, inspecting several of the Landsat imagery prints, the same interpretation can be made. The best contrast is evident in bands 5 and

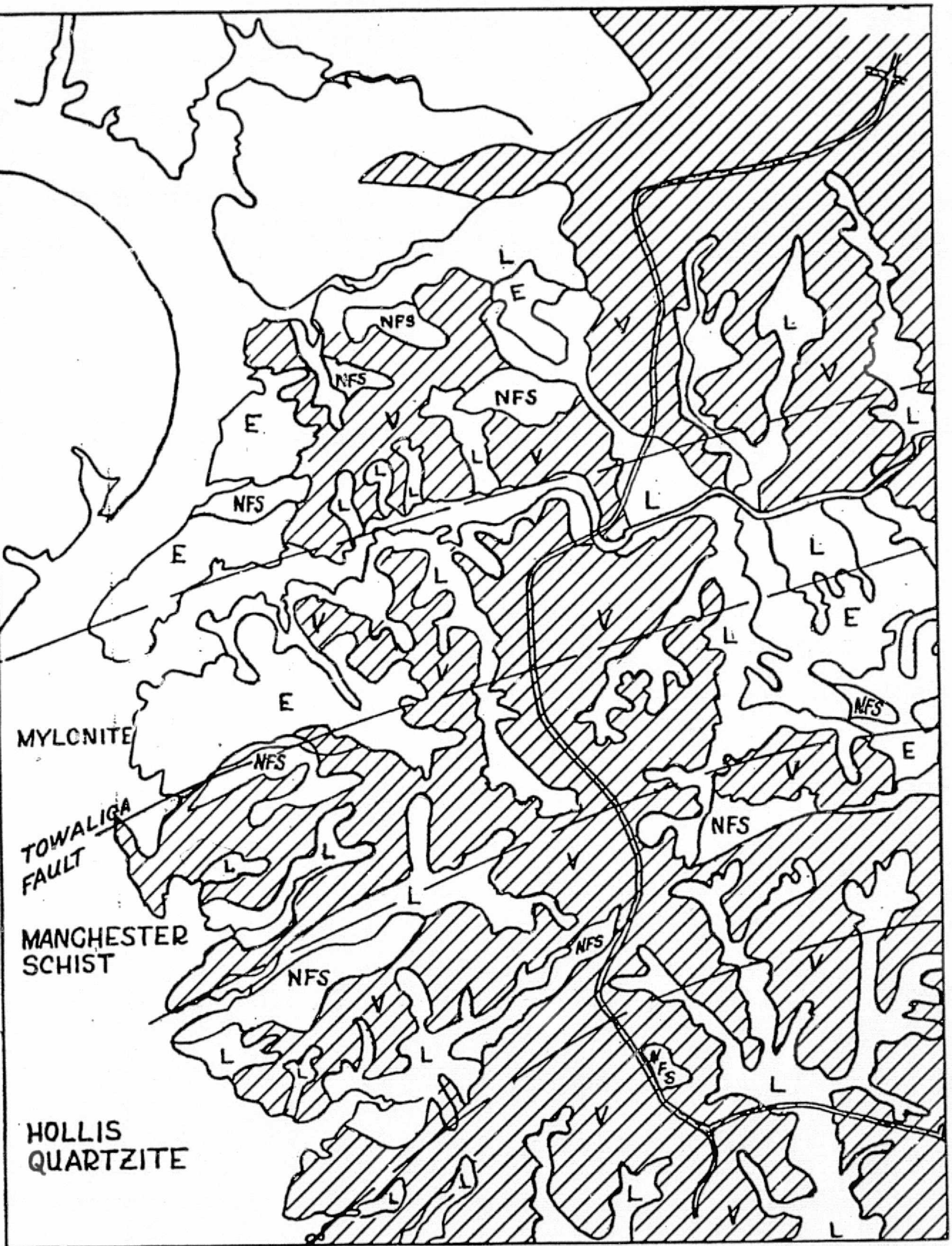

Fig. 11 - Vegetation map of the Pine Mountain area. Same coverage and scale as Fig. 10. Shaded areas represent upland pine communities. See text for symbols.

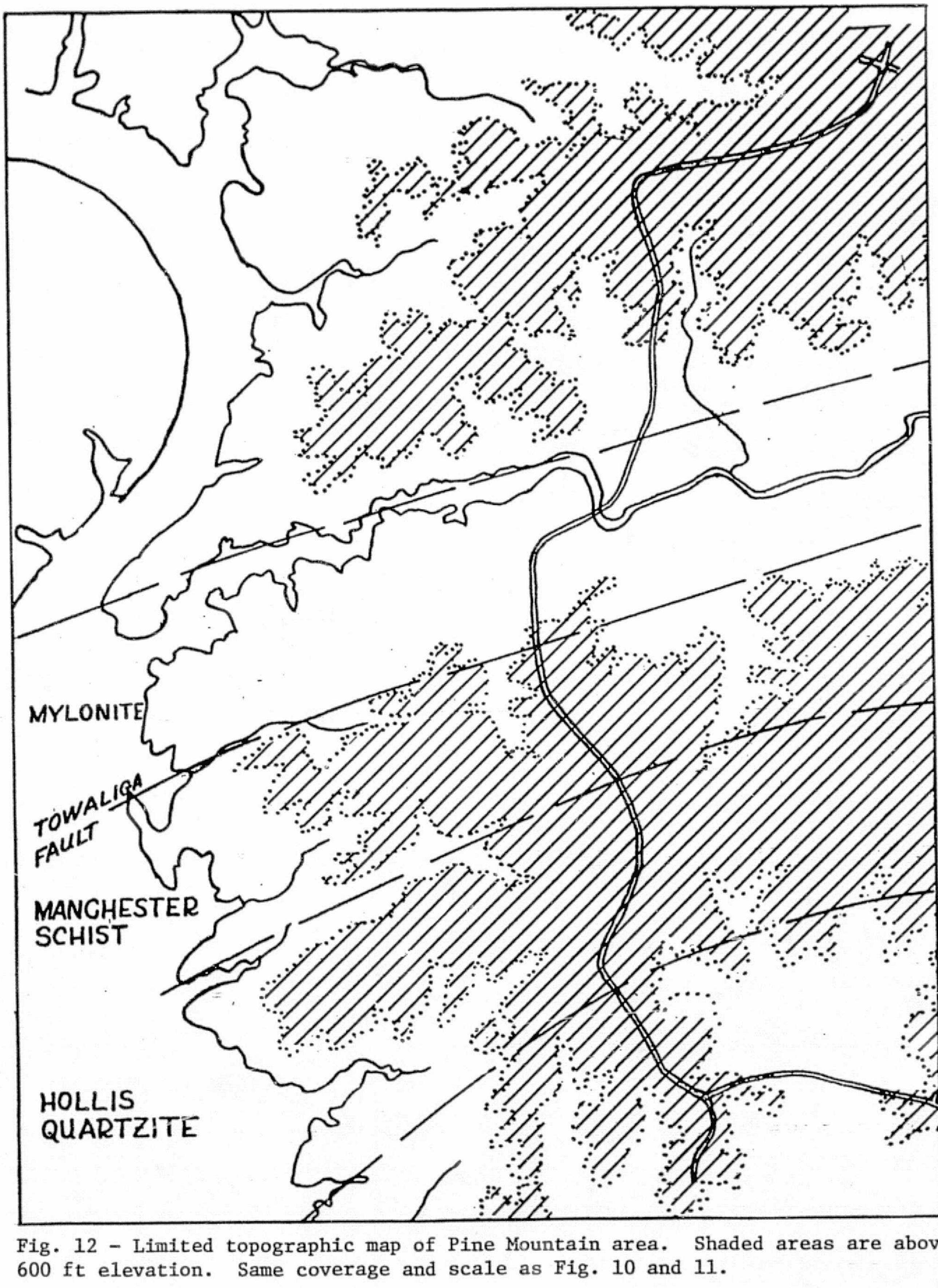

Fig. 12 - Limited topographic map of Pine Mountain area. Shaded areas are above 600 ft elevation. Same coverage and scale as Fig. 10 and 11.

7 of the multispectral scanner. The springtime (April 13, 1972) is more informative than the autumn (October 15, 1972) for the same wavelength band. Using prints which are 29.2 inches square the scale is 1:250,000. The distinctions are more readily evident on the single band chip or print than on the false color composite (FCC) print of bands 4, 5, and 7 for the April 13, 1972 imagery. Since some of the resolution, present in the raw data as received from Landsat, is sacrificed in processing to produce the printed imagery it is assumed the vegetative features, and indirectly the geological features, could be evaluated by digital techniques to provide subclasses within the vegetation, possibly even separating the north-facing slopes from other land forms. The north-facing slopes (NFS) recorded on the map in Figure 11 range from 5 acres to 30 acres. Landsat data as originally received should be able to resolve units of this dimension.

VII. SINKHOLE INVESTIGATIONS

A. Introduction

1. Sinkhole problem

Surface collapse in urban areas and along highways is a major problem in many parts of the world. It is frequently a factor in designation of land use in community development and in location of arterial roadways because, directly or indirectly, the nature of the developmental activity can influence the severity and economic impact of sinkhole occurrence. Recognition of potential collapse locations can often reduce the hazards by indicating safe construction sites as well as areas that should not be occupied or from which excessive ground water withdrawal should not be made.

Collapse occurs most often in regions underlain by limestone, but can also occur where there has been underground mining and quarrying or where old surface quarries have been filled with rubble or soil. In some

places, especially in Europe, underground quarrying was discontinued as long as several centuries ago and all records of the workings have disappeared, so it comes as a great surprise when collapse occurs in granite or other normally stable terrain (Omnes, 1975).

Prediction of where or when collapse will take place is not entirely a matter of locating underground cavities. Depth and size of a cavity and nature of the roof are obvious factors. Even in areas where limestone is the surface formation, sinkholes may be relatively rare if there is a thick clay soil and the water table remains high. The answer to how an area of potential collapse should be developed depends upon a thorough knowledge of the underground formations, including location and size of cavities, plus consideration of the effect of the projected development on changes in surface and subsurface conditions, especially as related to water runoff and groundwater entry, withdrawal and lateral movement.

Obtaining the necessary information can require time and effort out of proportion to the value of the land if conventional methods of evaluation by systematic core drilling are employed. A multistage program, involving surface criteria which could be monitored by selective geophysical studies and minimal drilling would probably be the most likely attainable objective. Our investigations in the sinkhole area around Albany, Georgia, suggest how such a program might be effected.

2. <u>Location and area</u>

The area chosen for investigation is centered around Albany, the county seat of Dougherty County and the largest city in southwestern Georgia. It is located on the west bank of the Flint River in the subprovince of the southeastern Coastal Plain known as the Dougherty Plain.

The project area consists of an east-west strip about 25 km long and about 11 km wide, between latitudes 31°31'N and 31°38'N; and longitudes 84°03'W and 84°18'W. This includes the city of Albany and northward to beyond the Lee County line. This area, within which surface geological and geophysical work was done, covers about 275 km^2. In addition, we have examined recent color infrared 1:24,000-scale photo coverage over a wider area which includes parts of Baker County, to the south, and Terrell County, located to the northeast of Dougherty County, for a total of about 1,000 km^2.

3. Scope of investigation

Albany is one of the most rapidly growing metropolitan areas in Georgia. Climate and topography are generally favorable, and present no obstacles to urban expansion. The sudden and unanticipated appearance of sinkholes, however, especially in areas of recent development, has introduced a geologic hazard of significant magnitude. The problem of precisely identifying locations of potential collapse has engaged the attention of several agencies. Our investigation was directed at this special problem.

Based on previous research in limestone terrain elsewhere, we believed that plant stress would identify cavernous locations that were most likely to collapse, and that a quantitative measure of the degree of stress could be determined by remote sensing methods. In the previous work, verification had been accomplished by drilling. While this certainly provided unequivocal substantiation of the presence of caverns, it was an expensive procedure. An important objective of our investigation was to find a more rapid and less expensive method of confirming the plant indications, preferably using portable geophysical equipment. Thus we conducted microgravity and electrical resistivity surveys across an area where sinkhole locations were precisely known, and extended the survey to adjacent land

where surface indications suggested additional sinks might be anticipated.

Available time and research funds limited the project to a feasibility study, but the results were sufficiently consistent to point to the reliability of microgravity and to discourage further experimentation with resistivity techniques.

4. Previous investigations

A significant study of the sinkhole problem was reported by Newton et al. (1973) from the Tuscumbia Limestone region near Bessemer, Alabama. More than 150 sinks and related features appeared on or near the proposed location of Interstate Highway 459, beginning in 1950 and continuing to the time of the study in 1973. Various methods were used to define the geological and hydrological conditions, including 253 auger holes, 16 core holes, a shallow refraction seismic survey, and the use of multispectral photography and thermal infrared imagery. It was concluded that cessation of pumpage from wells and mines had resulted in conditions favorable to the recovery of the water table and that a return to pre-1950 conditions should greatly reduce the incidence of collapse. It was noted that plant stress related to the lowered water table could be identified from the remote sensing data.

The application of remote sensing techniques in detecting possible sinks in the Albany area was investigated by Barr and Hensey (1975). The project concerned evaluation of an industrial site where there was interest in determining the location of subsurface solution zones prior to factory layout and foundation design. An area of about 200 hectares was photographed with color and color infrared film, from which an interpretive map was prepared showing suspected solution zones and potential sinkholes. The indicated problem areas were investigated by bore-hole and approximately

85% of the inferred solution zones were confirmed by the borings.

The Georgia Geological Survey and the Southwest Georgia Planning and Development Commission have been concerned with the sinkhole problem and have carried out preliminary studies to determine the cause of the sinks (Wilson and Pickering, 1973). An investigation was conducted by the Hydrology Section of the Geological Survey in 1976 to determine the feasibility of using electrical resistivity methods to delineate caverns. The program was under the direction of Dr. Barry Beck, who reports (personal communication) that the technique is not feasible. This confirms our own experiments in the area using similar equipment.

Microgravity surveys have been successfully conducted by Geoterrex, a subsidiary of Compagnie Générale de Géophysique, for about 10 years, with most operations being conducted in Europe and related to the location of both natural and man-made cavities (Neumann, 1972; Omnes, 1975). A special "Microgal" gravity meter, built by Lacoste and Romberg, Inc., has been used for this work exclusively since 1971, although successful searches for caverns, using good conventional gravity meters, were described as early as 1963 by G.C. Colley. The techniques used in our surveys were modified after the experiences described by these earlier workers and in consultation with gravity specialists from Geophysical Service Inc. of Dallas, Texas.

B. Geology

The Dougherty Plain is underlain by the Ocala Limestone of Jackson (Late Eocene) age (Brantly, 1916). In the Albany area it is a creamy white to light-gray, medium to coarse-grained, clastic limestone, and is generally poorly bedded and soft. It ranges in thickness from 20 to 100 meters, with the increase in thickness occurring towards the southeast. Chemically, the Ocala is a remarkably pure limestone. The results of 12

chemical analyses were reported by Wilson and Pickering (1973, p. 12):

	$CaCO_3$	SiO_2	$MgCO_3$	Al_2O_3	Fe_2O_3
Average of 12 samples	97.86	0.60	0.28	0.50	0.14
Maximum %	99.31	1.62	0.50	1.04	0.20
Minimum %	96.02	0.16	0.20	0.10	0.10

A prominent characteristic of the Dougherty Plain is the abundance of sinkholes, which may range from less than 30 cm to more than 300 meters in diameter. The region has both surface and subsurface drainage, with evidence for the latter being found in disappearing streams, springs, and caverns. There seems to be a fairly even exchange of water between the two drainage systems. Some streams may plunge into a sink and thus charge the subsurface system, while a nearby spring might feed a surface stream. During times of extended drought the ground water level falls and some springs may cease to flow. If the spring is in a stream bed and the stream continues to flow, water can enter the aquifer by reverse flow through the spring outlet.

The predominant soil type is a tan to dark red residual clay which is impermeable and often poorly drained. Chert boulders and fragments are common in the soil. In some areas there is a veneer of sandy or silty alluvium from the Flint River flood plain.

Sinkholes

Sinkholes and other manifestations of near-surface solution may occur wherever calcareous rocks lie within the zone of groundwater movement. Not all of the approximately 10% of the earth's land surface that is underlain by carbonate rocks is affected by solution phenomena, but virtually all that lies within climatic zones of moderate or greater rainfall is affected to varying degrees. In some areas of high land values and concentration of

construction projects, this has become a serious factor in land use and development planning. The problem has become especially acute in the Albany area, and state, local, and private groups are working to solve the dilemma. Present effort is directed mainly at devising methods for identifying potential collapse sites and in minimizing the damage where collapse has occurred.

Wilson and Pickering (1973) have reviewed a number of case histories of collapse in Dougherty County. Several have developed around the Albany municipal airport and it is suspected that areas on runways in chronic disrepair may indicate additional activity. An interesting occurrence was reported at Banks-Haley Art Gallery, a brick building located in the northwest part of Albany. Heavy rains occurred during the afternoon of June 6, 1973, with subsequent ponding of several feet of water in a depression behind the gallery. This apparently triggered its collapse about 8:00 p.m. Starting as a drain and growing rapidly, by morning it had reached a size of 8 meters in diameter and 4.5 meters deep. Sandbagging operations were largely ineffective in holding back the inflow of water. A second collapse appeared behind the sandbags, and after more sand was brought in, a third collapse occurred. During the following day the sink had drained 6 meters to the top of the limestone.

The Georgia workers (Wilson and Pickering, 1973, p. 27) present the following observations as contributing factors in sinkhole formation:

1. Periods of drought, broken by sudden heavy rainfall. The dry soil cover is suddenly saturated with moisture and loses its bridge strength.

2. Ponding of standing water over areas of former or potential collapse (Fig. 13-16). This may be caused by impounding of small ponds or lakes in shallow depressions which remain from former sinks that may now

be plugged. Once downward flow of ponded water begins through a small vertical drain passage, slurrying and stoping of residual soil begin, and collapse can be rapid.

3. Loading of potential sink areas by heavy structures such as apartment houses, industrial buildings, and highway overpass or bridge footings.

4. Vibration caused by mine blasting, industrial operations, railroad or airport operations, may aggravate collapse conditions in critical circumstances.

5. Underground injection of fluids, such as by broken water lines or by fluid pressure associated with drilling operations. A slight collapse can cause a break in a water main which will then make a slurry of the soil and set off more rapid and larger subsidence.

6. Excavation of residual soil over incipient collapse areas can reduce bridge thickness and cause sudden or gradual failure.

7. Abandonment of test or other drill holes in low areas where flood waters can drain to subsurface near underground caverns. This can localize slurry and drainage of soil into caverns, causing collapse.

8. Filling collapse craters with loose fill or sand which has little cohesion. Craters are likely to collapse again under the added weight of new structures, or be washed into subsurface by subsequent floods.

C. Botanical Aspects of Sinkhole Problem

1. Vegetation in areas of potential sinks

Within the city limits of Albany, Georgia, and throughout the immediately adjoining area the appearance of sinkholes has become an increasing problem in recent years. Most of the original vegetation has been radically altered throughout this area by urban development. On level land the

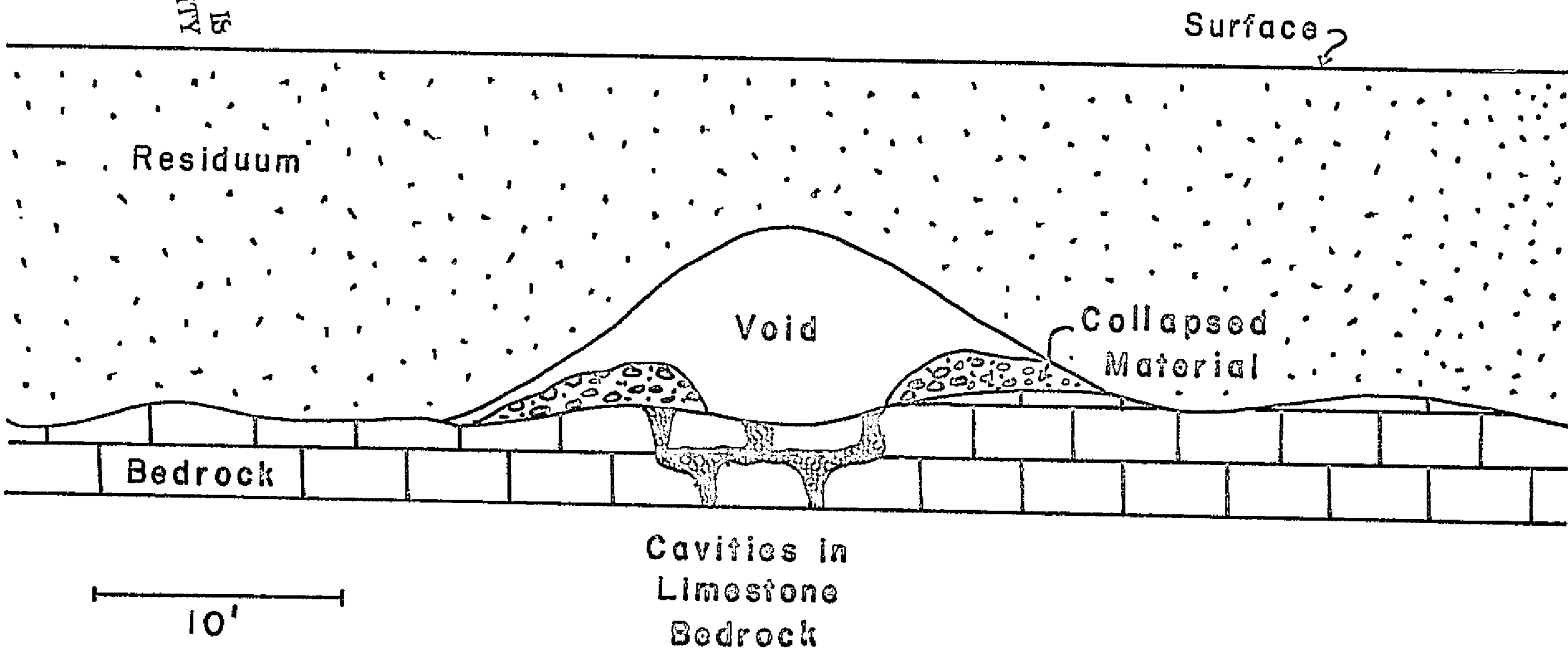

Fig. 13 Initial stage in development of sinkhole. Lowering of water table results in stoping of residuum from below as downward-moving water carries weathered material away through cavities.

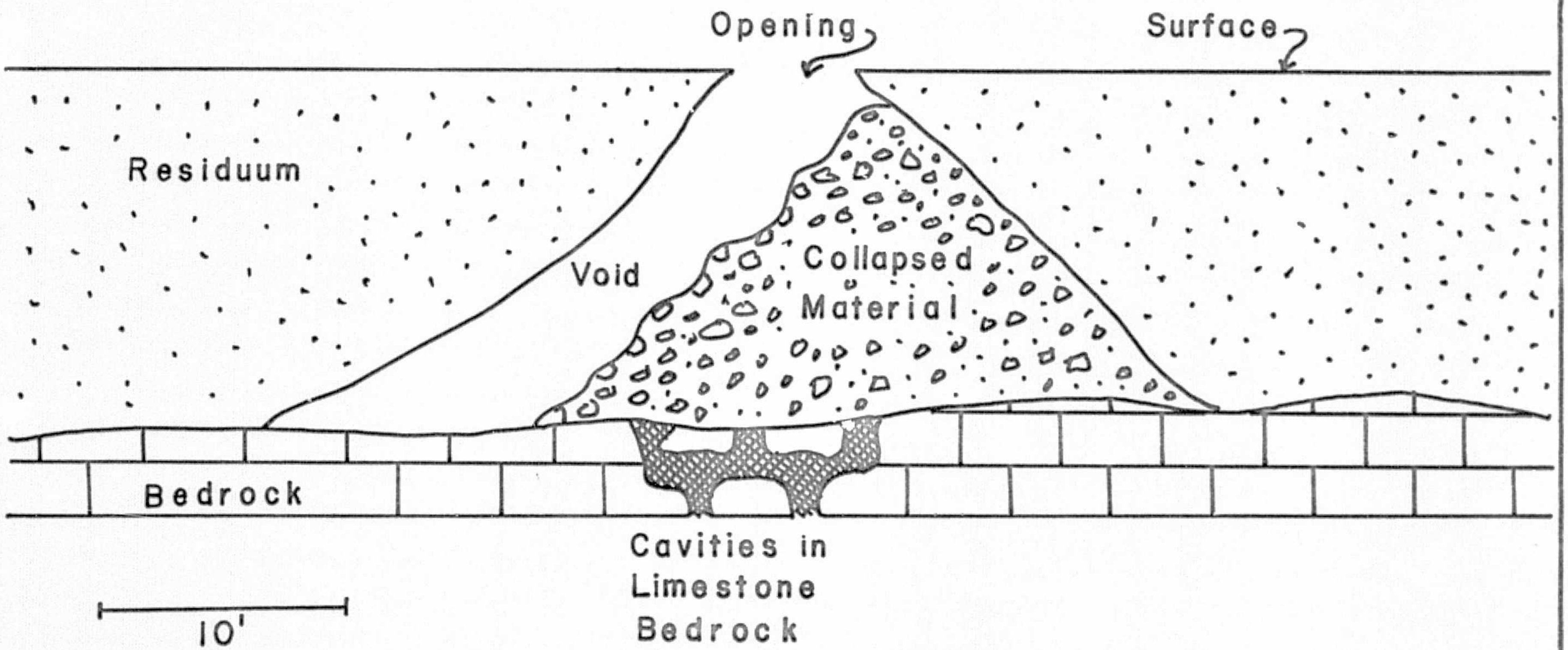

Fig. 14 Youthful stage in development of sinkhole. Collapse of residuum bridge reaches surface, allowing run-off water to enter void and enlarge it further. (After Wilson & Pickering, 1973)

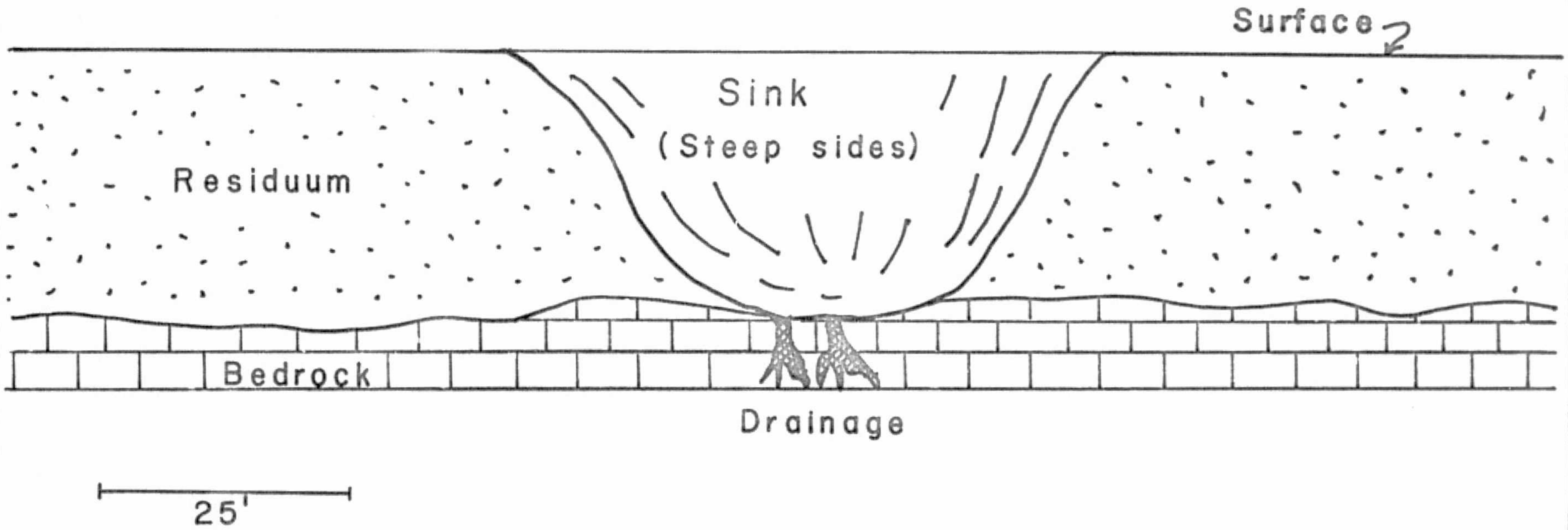

Fig. 15 Intermediate stage in development of sinkhole. Sink is fully open to surface; water moves rapidly downward when water table is below bottom of sink. (After Wilson & Pickering, 1973)

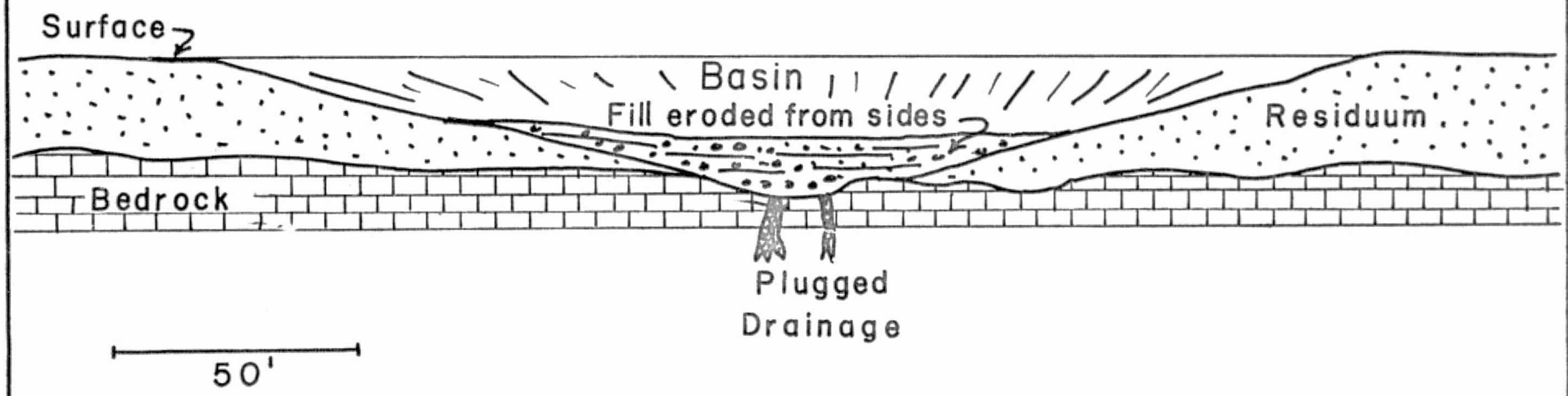

Fig. 16 Final stage in sinkhole development. (After Wilson & Pickering, 1973)

original forest has been replaced by agriculture, sylviculture, and the man-made buildings, pavements, lawns, and parks of a modern city. The agricultural crops are primarily pecan orchards and annual crops as winter wheat, corn, and soybeans. These portions of the ground are covered with plants which may be subjected to further man-induced changes by irrigation, fertilizer applications, mowing, or heat stress brought about by the presence of buildings and pavements.

The drainage patterns, less suitable for immediate and direct use by man, are generally forested with a mixed lowland community comprising hardwood species as: water oak (_Quercus nigra_), willow oak (_Q. phellos_), magnolia (_Magnolia grandiflora_), sweetgum (_Liquidambar styraciflua_), tulip poplar (_Liriodendron tulipifera_), holly (_Ilex_ sp.), several species of smilax and Spanish moss (_Tillandsia usneoides_) commonly present.

The concern over occurrence of new sinkholes is primarily in the areas of urban expansion and development rather than in the lowland forested areas. This is vegetation which is maintained by man and subjected to both short and long-term alterations.

2. Recognition of plant stress due to water privation

Energy in the near infrared portion of the electromagnetic spectrum (0.7 to 1.5 μm) is reflected from vegetation in variable amounts depending on the plant species and its environmental and phenological conditions. The hardwoods and grasses in the Albany area are putting out new growth in early April, and appear as bright red patterns on CIR imagery at that date and later. Those agricultural fields which are irrigated and the lawns receiving water continue to show this same signature as summer advances. Plants without sufficient groundwater begin to show changes in their IR reflectivity as they close their stomates, reduce transpiration, and thereby allow their leaves to reach a higher temperature (Morain, 1974). The

identification of water stress by increased IR reflectivity can be made on CIR photography. This enables a photointerpreter to pinpoint spots of reduced groundwater, dependant on the scale of the photography, which may represent sites of incipient sinkholes. Landsat and Skylab imagery lack sufficient resolution to permit discrimination of such small features; however, aerial IR photography provides ample resolution at a scale of 1:24,000 to identify existing sinkholes of less than 30 meters in diameter. The larger sinkholes, over 300 meters in diameter are in evidence on the Landsat and Skylab imagery.

Since many environmental variables besides water stress may influence IR reflectivity the reliability of photointerpretation for identification of potential sinkholes will depend more on the experience and knowledge of local vegetation and conditions on the part of the photointerpreter than on the limits of resolution of the imagery. Further, imagery must be made when the soil conditions are conducive to producing vegetation stress above a potential sinkhole, but not in the adjacent subsoil. This is often an ephemeral situation, which is erased by rainfall, or continued drought. Constant real-time surveillance would be ideal, (i.e., Nimbus satellite) or precise timing of photographic flights would be acceptable if these conditions could be determined in advance so as to supply close to real-time interpretation of imagery.

D. Microgravity Investigations

The feasibility of recognizing small, shallow gravity anomalies is not a new concept. It has seldom been attempted as a practical part of gravity programs, however, because mineral or petroleum occurrences do not commonly relate to such a structural situation and the techniques employed in recognizing the small anomalies are much more time consuming than those normally used.

High-sensitivity gravity meters have been constructed but are not widely used. Initial cost, extra care and repairs, and the relatively few times such sensitivity is needed, have limited their distribution. Results approaching those attainable by "Microgal" meters can be achieved with high quality conventional gravity meters if speed of survey coverage is not a factor. Close spacing of gravity stations, with frequent cross checks and perhaps repeated readings, combined with careful elevation control, will provide the sensitivity needed for location of caverns that are likely to be large enough to result in surface collapse or foundation problems. While the area covered by this detailed microgravity technique will not compare favorably with daily production rates of a conventional gravity program, the cost of the microgravity work will be far less than a sinkhole investigation employing boreholes or shallow-reflection seismic methods. The procedure described here can probably be used with good results in any temperate climate limestone region. The Albany area is especially well suited to the method because there is little topographic relief, so this factor in reduction of the data to the Bouguer gravity field is minimal.

1. Area investigated

Gravity and electrical resistivity surveys were conducted along two intersecting traverses located in a part of the city of Albany that is now undergoing building development. The area is in the northern part of the city and is bounded by Palymra Road and the Seaboard Coast Line railroad tracks (Fig. 17); it covers about 250 hectares (630 acres).

A southeast line approximately 600 meters long was run from Phoebe Putney Hospital to the Shrine Temple and a northeast cross line of 450 meters extended from Palmyra Road to the railroad tracks. About 75

hectares, located at the southern end of the project area, contains the grounds of the Masonic Lodge and Shrine Temple, including outbuildings, which have been occupied for a number of years. The remaining area is under development as a medical complex, and presently includes a large hospital, nursing home, and two buildings devoted to offices and clinics. One large active sink on the Shrine-Masonic property has defied efforts to contain it and is presently expanding. It reaches the top of the Ocala Limestone about 9 meters below ground level. Four known sinks have occurred since building was started on the northern portion of the area, two of them appearing during 1976. Further development eastward towards the railroad track is contemplated, and our preliminary analysis indicates that sinks will follow soon after.

2. Techniques

Gravity readings were taken with a Worden "Prospector" type gravity meter at stations located at 10 to 12-meter intervals. Surveying was by plane-table and self-leveling alidade, with control accuracy of 10 cm horizontally and 1 cm vertically. Gravity readings were made to 0.01 milligals and appear to be accurate to 0.02 milligals. Elevation and latitude corrections were calculated by a standard computer program and Bouguer values determined. Variations across small sinks were in the range of 0.280 milligal, and a maximum difference on the two traverses was 0.804 milligal.

Readings were also made at each station with a Geometrics Model G-826 portable magnetometer, with sensitivity of ± 1 gamma; and electrical resistivity readings were taken with a Soiltest Model R-40-C meter, employing 100-foot probes.

3. Results

The magnetometer and resistivity surveys were inconclusive.

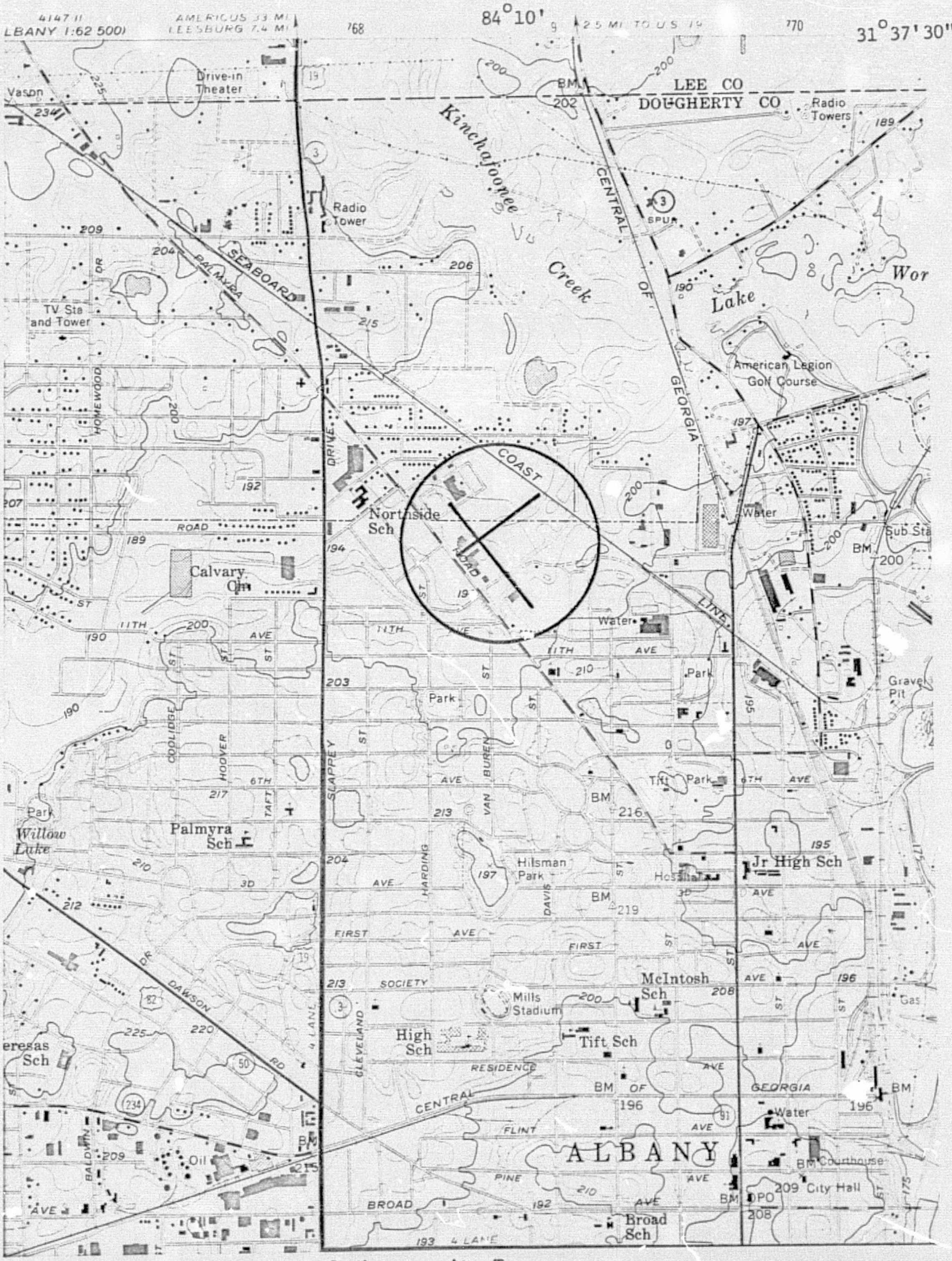

Fig. 17. Location Map of Microgravity Traverses.

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Electrical power lines and buried pipes resulted in so many anomalous spikes that variations caused by natural differences could not be identified with certainty. A resistivity survey in the Albany area, conducted by a hydrologist with the Georgia Geological Survey at about the same time and using similar equipment, was abandoned as not feasible for both observational and theoretical reasons. The experience of these investigations discouraged further efforts and we have no plans for additional projects.

The small gravity differences make determination of the bottom of subsurface cavities uncertain and reduce the confidence of quantitative profiles. However, as an indicator of the location of potential or past sinks the method is successful. The project area was recommended by J.D. Wilson, Supervisory Geologist of the Coastal Plains office of the Georgia Geological Survey in Albany, because three sinks had occurred there within the past year and their exact location was known. There were in addition two open sinks, including the large one in the southern part of the area where the top of the limestone could be seen.

Negative gravity deviations were obtained at every known sink location. In one instance a slightly elevated surface area seemed to be underlain by low-density material. Further investigation revealed that this had been a collapse site early in the development of the northern portion and had been filled with sand, soil, and rubble.

A subsequent microgravity survey was conducted by other members of the Earth Science Department of the College in another part of the Dougherty Plain, and a similar pattern of probable caverns was revealed. On this project a 60-meter grid with 10-meter station spacing was used. We recommend a regularly spaced grid as probably the most effective technique for evaluating a plot of land. The resulting data points provide good control

for contouring gravity values and revealing anomalous locations indicative of caverns or filled sinks.

E. Discussion of Results

1. General applicability of method

Microgravity surveys have been defined as surveys where the accuracy of measurements is better than 0.05 milligal and the spacing between stations less than 100 meters (Omnes, 1975). Gravity meters with a sensitivity of 0.01 mgal have been available since 1940, but seldom is accuracy greater than 0.05 mgal required in petroleum or mineral prospecting. Gravity is generally regarded as a reconnaissance tool, and the gravity survey often supplements seismic so that gravity readings are taken at seismic shot points, frequently located on 100-meter spacing with grid lines several kilometers apart. The corresponding gravity net is useful only for detection of relatively large features, and the contour interval of Bouguer values is from 1 to 5 mgals.

Experiments with precision gravity surveys have been described since the 1940's. For example, Hammer et al. (1945) conducted a survey in Cuba where chromite bodies of less than 100 meters in width were sought. Siegal et al. (1968) used microgravity methods to define a lead-zinc ore body where the top of the ore was at a depth of about 10 m and its maximum thickness was about 25 m. In both instances there was significant density contrast between the ore bodies and the surrounding rocks. In the lead-zinc prospect, the density of the ore body was 3.95 g cm^{-3} and the surrounding limestone was 2.65, the effective difference being 1.30 g cm^{-3}. In the case of limestone cavities filled with water, the difference would be about 1.65, essentially the same order of density contrast as with the mineral prospects.

Compagnie Générale de Géophysique carried out microgravity surveys for the detection of cavities in 1963 near Paris, France, as part of

a major highway construction program (Neumann, 1972; Omnes, 1975). Since that time CGG has developed the technique and encouraged the manufacture of an especially sensitive gravity meter for this work. Gravity has proved to be superior to electrical methods in locating cavities, to the point that the other methods have been discontinued by CGG in their European operations.

Experience to date indicates that success in identifying cavities or filled depressions in limestone country depends primarily on reducing the sources of error in computation of Bouguer anomaly values and in designing a survey grid that will provide close control so as to take into account relatively small anomalous bodies.

The first requirement - that of reducing computational errors - is well within the control of the operator. The accuracy of instrument readings can be improved by multiple observations. It may be worthwhile to reoccupy a station two or three times and use an average reading. Careful land survey methods in location and elevation of stations can reduce latitude and elevation (free-air) corrections so that they are not significant factors. For example, an error in elevation of 3 cm would change the gravity value at a station by 0.007 mgal, and an error of 3 m in the north-south coordinate of position would result in an error of 0.003 mgal at middle latitudes. These tolerances can easily be met with plane-table and alidade surveys in most areas.

Topographic correction varies with the local terrain, but a skillful observer can minimize the inherent error. The Bouguer correction can be accurately estimated if knowledge of the rock types is properly employed. Earth-tide corrections are unlikely to be a problem if base-station ties are made at proper intervals during each survey day.

2. Application of microgravity technique in the Albany area

The Albany area is almost ideal for microgravity work. The geology is relatively simple and predictable. There is little topographic relief, so plane-table surveys can be run rapidly and terrain corrections are negligible in most places.

Our observations support those of Barr and Hensey (1975) in imagery and photography, especially thermal and color infrared film, can be interpreted to yield a map of probable sinkhole and solution zones. Reliable estimates of the residual soil thickness can usually be gotten from the Albany Health Department, which has a file of 2,400 water-well logs, or from auger holes drilled throughout the county by the Georgia Geological Survey. With the "sinkhole potential" map and an estimate of soil depth as a starting point, a gravity program can be laid out.

We have averaged 10 stations per hour with two persons doing the topographic surveying and two handling the gravity readings. More experience with the method is certain to increase daily production.

Ultimately the method should be tested by drilling. We have plans for further surveys in the Albany area and are especially anxious to survey a prospect that will be drilled. The work to date is not a definitive test of the method, but all indications are that it is successful.

VIII. ANDERSONVILLE AREA

A. Introduction

1. Location

Andersonville is a town in northern Sumter County, Georgia, from which a kaolin-mining district takes its name, as does a famous Civil War prison, now a National Cemetary and historic site. The mining district

extends into Schley and Macon Counties and forms a northwest-trending strip about 22 km long and 10 to 13 km wide, covering an area of about 250 km^2 (Fig. 18). It appears to be restricted to formations of Lower Eocene age. The area of investigation was confined to the kaolin belt and within the boundaries of 84°00'W to 84°09'W Longitude and 32°05'N to 32°17'N Latitude.

2. Objectives

Kaolin and bauxite occur as sedimentary bodies of variable purity, and are mined beneath an overburden up to 15 m thick. Frequently the cover is thinner than 2 m, and only a poorly developed soil layer overlies the kaolin. There is a saying among the long-time inhabitants of the area that kaolin will most often be found where pine is scarce and "scrub" oak dominates the tree cover.

The Andersonville district was investigated for its aluminum potential as a joint U.S. Geological Survey and Bureau of Mines project, and a fault which has come to be known as the Andersonville fault, was located by Zapp (1943) on the basis of stratigraphic offset. Later workers (e.g., Owen, 1963) have supported this interpretation and the possibility of further faulting has been suggested.

Our objectives were (1) to determine whether or not buried kaolin bodies were revealed by the plant cover and (2) if structures, especially faulting, could be identified on the remote sensing documents.

B. Geology

1. General description

The Andersonville district is underlain by about 750 m of Coastal Plain sediments of Cretaceous and Early Tertiary age resting on metamorphic basement of Piedmont aspect (Milton and Hurst, 1963). These sediments are relatively undisturbed and dip gently south and southeast.

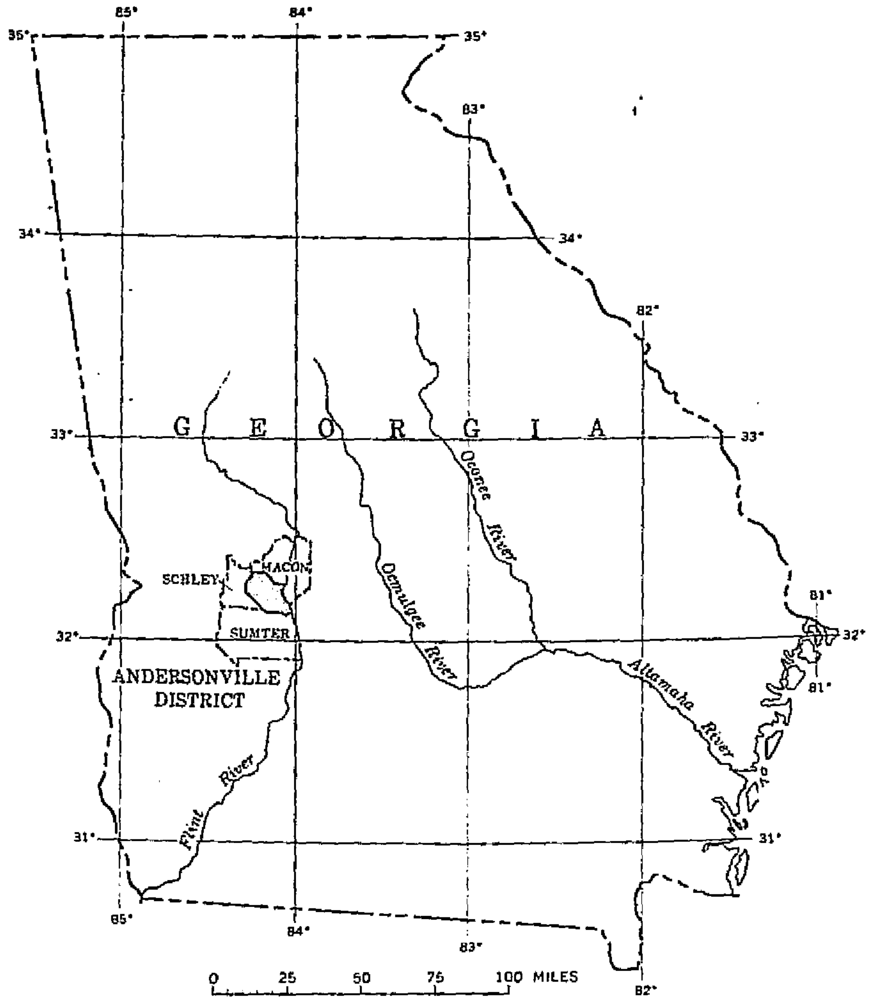

Fig. 18. Location Map of Andersonville District

The stratigraphic section is illustrated in Fig. 19.

The oldest formation exposed in the district is the Providence Sand of Late Cretaceous age, consisting of poorly sorted micaceous sand containing some clay, including lenses and fragments of kaolin. The Providence Sand is unconformably overlain by marine clay and limestone of Paleocene age and attributable to the Midway Group. Correlatives of the Clayton Limestone and Porters Creek Formation have been recognized. The best outcrops occur along the Flint River, where they were examined by the writers in bluffs north of Montezuma.

The Midway beds are overlain unconformably by neritic, lagoonal, and perhaps non-marine beds apparently of Sabinian age which are correlated with the Nanafalia and Tuscahoma Formations of Alabama. The Nanafalia Formation in the Andersonville area is 15 to 25 m thick and consists chiefly of micaceous sand and sandy clay containing lenses of kaolin and bauxite. Carbonaceous beds, which are often lignitic and pyritic, are sometimes associated with the kaolin lenses. The bauxite occurs as cores surrounded by relatively thick masses of clean, sand-free kaolin.

In the southern part of the district the Nanafalia Formation is overlain in places by remnants of the Tuscahoma Formation, which is probably of Early Eocene age. Here it consists mostly of interbedded yellow and dark-gray silt or fine sand. Zapp (1963) reports that the Tuscahoma is preserved in depressions on the irregular surface of the Nanafalia Formation and that it pinches out against topographic highs.

The Paleocene and Lower Eocene units are unconformably overlain by a clastic formation assigned a Middle Eocene age and correlated with the Tallahatta Formation of the Claiborne Group. The formation consists of 10 to 30 m of white to yellow sand, well-sorted and commonly crossbedded.

AGE		GRAPHIC LOG	THICKNESS (Meters)	FORMATION DESCRIPTION
Tertiary	Eocene		6	Residuum from U. Eocene and younger.
Tertiary	Eocene		14	Claiborne Group - McBean Formation: Marl, sandy, glauconitic, fossiliferous.
Tertiary	Eocene		30	Tallahatta Formation: Sand, phosphatic.
Tertiary	Eocene / Paleocene		18	Nanafalia Formation: Variegated white to brown, highly micaceous clay and sand. Kaolin and bauxite of the Andersonville and Eufaula Districts.
Tertiary	Paleocene		9	Midway Group - Sand unit.
Tertiary	Paleocene		6	Clay, gray to black, carbonaceous.
Tertiary	Paleocene		15	Clayton Limestone: gray, sandy, fossiliferous limestone.
U. Cretaceous			45	Providence Fm: Red clay and sand.
U. Cretaceous			40	Ripley Fm: Sandy marl.
U. Cretaceous			30	Cusetta Sand.
U. Cretaceous			300	Blufftown Formation: Sandy clay and sand
U. Cretaceous			60	Eutaw Formation: Sand and sandy clay.
U. Cretaceous			60	Tuscaloosa Formation: Sand, kaolinitic
L.Cret.			116	Sediments of Comanchean age: Sand and clayey sand.
Tr.				Triassic redbeds of undetermined thickness.

Fig. 19 Stratigraphic Section, Andersonville District

It differs from sands of the Nanafalia in being well sorted and containing little mica. On flat divides the sand is impregnated with clay and iron oxide, resulting in a brick-red soil (Americus loamy sand) that makes good agricultural land.

The Tallahatta sands are capped by distorted sand and clay, probably representing residual beds of Jackson (Late Eocene) age and by scattered masses and nodules of chert derived from limestones of Jackson and Vicksburg (Early Oligocene) age. The unit cannot properly be considered a formation, although it has been called Flint River Formation (Cooke, 1943). It is believed to represent the decalcified and silicified remnants of the Ocala and Suwannee Limestones and associated clays.

2. Bauxite and kaolin deposits

The kaolin bodies of the Andersonville district are restricted to the Nanafalia Formation (Zapp, 1963). The lenticular masses of clean or sandy kaolin vary from 30 cm to 15 m in thickness and from 1 hectare to 1,000 hectares in areal extent (Cofer et al., 1976). Lenses of relatively pure kaolin grade vertically into sandy kaolin which passes gradually into kaolinitic sand. Laterally the transition is by interfingering of sand and kaolinitic lenses rather than by gradation.

Bauxite is sometimes present as a central core in the kaolin masses. The bauxite is composed of well-crystallized gibbsite and pisolitic kaolinite. Lenticular bauxite masses grade into the kaolin through zones having pisolitic structure. The bauxite bodies seldom exceed 3 m in thickness or extend over an area of more than 1 hectare.

3. Structure

Regional dip is to the southeast and varies from about 4.7 meters per kilometer on the top of the Cretaceous surface to about 2.8

meters per kilometer on the top of the Tallahatta Formation.

Zapp (1943) was the first to identify faulting in the Andersonville district. At that time there were few documented faults in the southeastern Coastal Plain, and considerable skepticism was expressed. One reason for the skeptical reception was that the Andersonville fault was proposed as up to the south, implying basement uplift counter to the normal faulting known in the coastal region surrounding the Gulf of Mexico.

The Andersonville fault was described as having a maximum vertical displacement of 30 m, and an approximately east-west orientation, with the upthrown block to the south.

C. Field Investigations

1. Botanical surveys

Four traverses for the collection of botanical data were followed in the Andersonville area (Fig. 20). Compass transects were walked to analyze and record the vegetation. Station intervals were located by taped distance, and plant species were tabulated within a 10-meter radius of the station.

Two traverses were established in areas of known kaolin deposits (Traverse I & II, Fig. 20) and two additional traverses (Traverse III & IV, Fig. 20) were located in areas where kaolin has not been found. The sites were in forest areas covered by NASA photographic missions of winter or spring 1976. Where possible, areas of overlapping coverage from both flights were selected. A description of the traverses follows:

Traverse I - Macon County, west of Andersonville National Historical Site (Fig. 20). A northwest transect was run from the point 32°11'43"N - 84°05'00"W, with stations located every 1000 ft. Five stations were established.

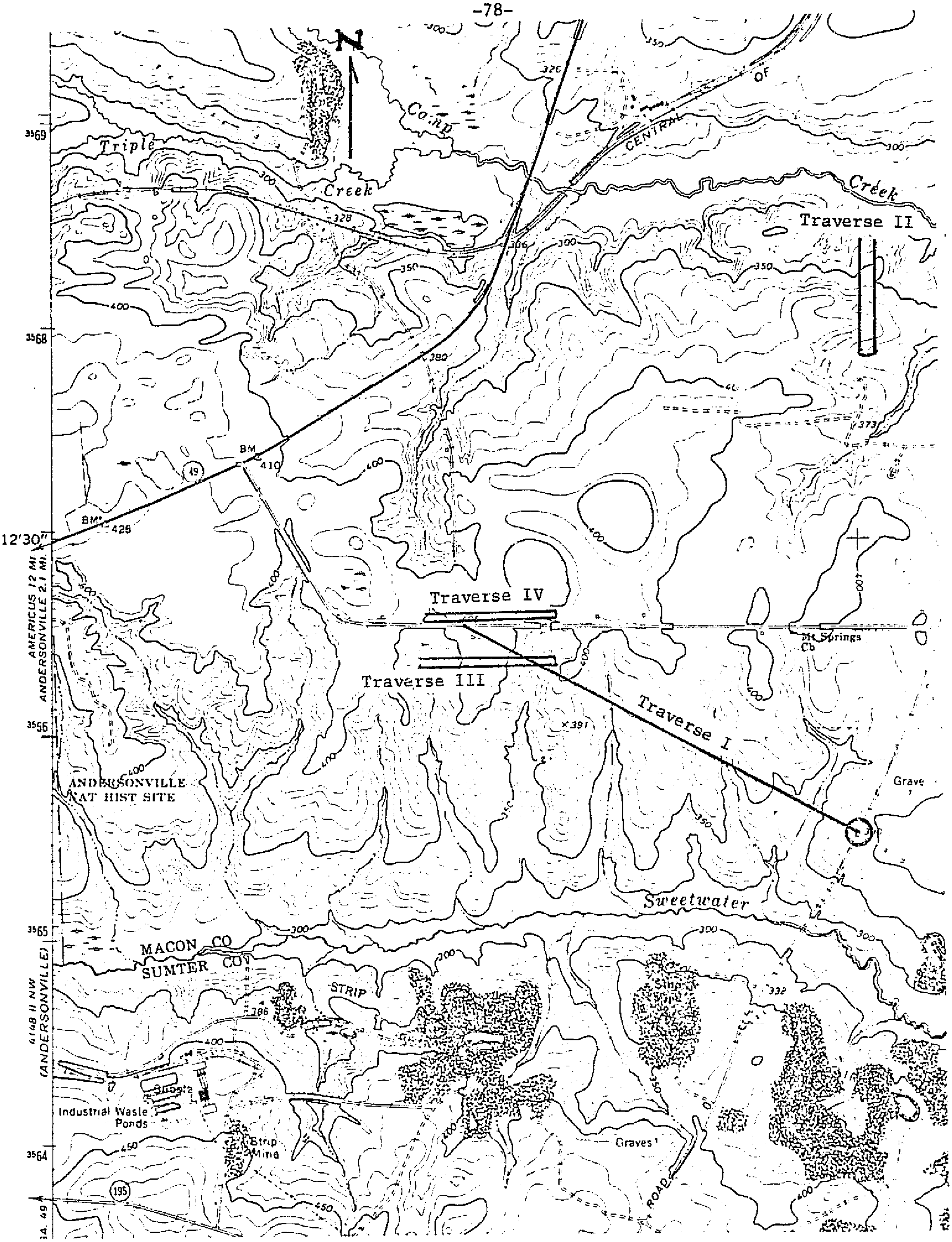

Fig. 20. Andersonville area, base map and location of vegetation studies.

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Traverse II - Macon County (Fig. 20). A south-to-north and north-to-south transect was completed, starting from the point 32°12'53"N - 84°05'00"W. Analysis was made every 500 ft for a total of 5 stations.

Traverse III - Sumter County (Fig. 20). South-to-north and north-to-south transects were carried out from the point 32°07'30"N - 84°01'30"W. Five stations 500 ft apart were analyzed.

Traverse IV - Sumter County (Fig. 20). Starting at the location 32°07'30"N - 84°01'16"W, 5 stations were established at 500 ft intervals on a south-to-north and north-to-south transect line.

For each station sampled an index of dominance and an index of diversity was calculated. The dominance index indicates the degree to which dominance may be concentrated in one, several, or many species, and shows the species' importance to the whole community. The diversity index is an indication of the variety of species that may be present in a given area and the diversity of the community. Mathematical limits for these parameters range from 1 to 0; values nearest to 1 indicate highest diversity and dominance. Tables 1 and 2 summarize this information.

TABLE 1

Species Dominance and Diversity Indexes by Station

		Traverse			
Station		I	II	III	IV
1	Dom.	.306	.552	.339	.349
	Div.	.669	.504	.628	.721
2	Dom.	.502	.331	.701	.659
	Div.	.450	.646	.297	.338
3	Dom.	.847	.452	.340	.391
	Div.	.181	.526	.766	.589
4	Dom.	.657	.603	.532	.342
	Div.	.956	.841	.536	.671
5	Dom.	.408	.423	.376	.353
	Div.	.662	.538	.672	.692

TABLE 2

Species Dominance and Diversity Indexes by Traverse

	I	II	III	IV
Dom.	.351	.332	.383	.341
Div.	.786	.569	.557	.559

2. Geological structures

Investigations during 1976 by ourselves and colleagues at Georgia Southwestern College and by members of the Georgia Geological Survey have revealed faults in the area not previously recognized. The investigations included a reflection seismic line on the Flint River, conducted in May 1976 by the Geological Survey, where 4 up-to-the-south faults involving basement were found along a 10-km traverse between Reeves Landing (32°07'25"N - 84°00'45"W) and Dripping Bluff (32°12'20"N - 84°03'20"W). This work was considered preliminary and the results have not been published. Further surveys are planned which will extend the coverage on the river and also attempt some parallel lines so as to obtain better information regarding direction of the fault planes.

Examination of the MSFC photography, especially the CIR coverage, reveals many linears. An outstanding example is in the vicinity of Reeves Landing west of Flint River where a cypress swamp has a very straight, narrow configuration. It is about 1000 m in length and oriented N65°W. It appears best on frame 36-20166 of the MSFC April 9, 1976, CIR photography. An eastward extension of the linear crosses the river at the point where a prominent fault was identified during the seismic survey noted above.

Ground investigation showed the swamp to be bounded on the south by a vertical scarp of river alluvium about 10 m high. A talus pile

has accumulated at the base and the cypress swamp is ponded along the scarp. To the west the trace dies out against a steep hill slope. It appears that the scarp may be the upthrown side of a fault. If this interpretation is correct, the faulting could be as recent as a few score years because it occurs in the river alluvium and has retained its steep face. A flowing artesian well is present along the road to Reeves Landing and about 100 m south of the swamp. Additional work, including gravity traverses, are planned for the area.

Faulting has been recognized in some of the kaolin pits, and we have picked other linears from photographs and topographic maps. A pattern of joints and faults is suggested, which will be used to guide the planning of further surveys.

D. Results

We can recognize a relationship between the vegetation and the relative amount of clay present in surficial beds. There is, however, no clear relation to kaolin as distinguished from other clays, nor does the relationship appear to be effective other than within the surface layers.

Analysis of data for individual stations shows some variations (Table 1) but the data between traverses does not demonstrate any significant differences except for the diversity index of Traverse I (Table 2). Along Traverse I there is greater topographic relief and a greater number of streams, which could be factors accounting for the higher diversity index.

In areas where kaolin is known to be present the Turkey Oak (Quercus laevis) has the greatest importance value and rates highest in dominance. In the areas where kaolin has not been found the largest importance value is registered by Short-leaf Pine (Pinus echinata). This distribution may be controlled by surface soil types and have no direct relation to underlying

kaolin deposits. The Turkey Oak appears to thrive in well-drained, sandy soils, while the Short-leaf Pine is found in soils with a higher clay content. Thus, the factors controlling distribution appear to be related to drainage and moisture retention more than to soil chemistry. Soils are primarily of the Lakeland-Americus association (Pilkinton, 1974). These are mainly well-drained to excessively drained sandy soils. Typically, the Lakeland soils have a dark grayish-brown surface layer about 20 cm thick, beneath which is yellowish-brown loose sand that extends to a depth of 2 m. Americus soils are excessively drained. In a typical profile the surface layer is dark reddish-brown loamy sand about 16 cm thick. The subsoil is dark-red loamy sand to a depth of 1.2 m, and the dark-red sandy loam to a depth of 1.8 m.

The remote sensing data have been of value in identifying linears that can be related to a pattern of jointing and faulting. Often this pattern is reflected in the vegetation, which is influenced by two factors: (1) fault scarps cause groundwater ponding and swamps with consequent swamp flora; (2) topographic effects of jointing or faulting cause local changes in slope with differences in drainage, which influence soil characteristics and thus have a bearing on vegetation dominance. We plan to use the imagery and infrared photography extensively in planning further geophysical work in the area.

TABLE 3

Tabulation of Plant Species in Andersonville District																		
Plant Species Tabulated by Station and Number of Observations	Traverse I Station					Traverse II Station					Traverse III Station				Traverse IV Station			
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	1	2	3	4
Alnus rugosa								2										
Carya sp.		1																
Cornus florida	9										2				3			
Cretagus sp.							7											
Diospyros virginiana											10	2			7		3	
Ilex opaca								1										
Liquidambar styraciflua												1						8
Magnolia virginiana		1					2	8										
Pinus echinata		1			13						19	25	10	27	2	23	14	17
P. palustris	3	1	3	6		5	3		3		3		7		6	3	5	1
Quercus alba	4	2		12		7	14	3		19								
Q. falcata											4	1		8	4		1	
Q. incana													6					
Q. laevis			33	16		8			18	12								
Q. margaretta									21									
Q. marlandica					7								1			7		6
Q. nigra	4	16			6			6										
Q. phellos										16								
Sassifras albidium						4												
Vaccinium arboreum														4				
Yucca filamentosa					2													

IX. AREAS OF LIMITED INVESTIGATION

All types of remote sensing data were examined for anomalous patterns that might lead to the identification of geological relationships. An evaluation of the various remote sensing media is given in Section X.

Some promising leads proved to be unrelated to geological or natural vegetation situations. For example, a region of several square kilometers in the Chattahoochee River valley of northwestern Stewart County, Georgia, showed a pock-mark pattern of light-colored areas in a relatively remote region of uncut natural forest. Ground investigation revealed that the land was used as a hunting preserve and the isolated light-colored patches were feeding stations for wild game. Abandoned quarries and strip mines, selective timbering, and areas of deep erosion gullies also make distinctive patterns which were investigated.

Three prospects are recommended for further work. Geobotanical relationships can be clearly demonstrated in one case and appear probable in the others. Lack of time, similarity to other projects under investigation, or relative travel necessary for further work were factors in deciding to limit the investigations of these areas. A brief description of each prospect follows.

A. Talladega Slate Belt

Geological and botanical observations were made across the Talladega belt between Sylacauga and Ashland, Alabama. The route followed State Highway 149 east from Sylacauga to Talladega Mountain at Bulls Gap; then north along the valley of Hatchet Creek to Chandler Springs. The route crosses excellent exposures of the upper portion of the Talladega Slate, including the Cheaha Sandstone Member and the Erin Slate. The area is within the Talladega National Forest and most of it has not been cut over.

The Talladega Slate comprises a succession of phyllite, arkosic sandstone, chert, and minor calcareous beds, that may exceed 5,000 m in thickness. These are generally low-rank metamorphic rocks that are separated from Lower Paleozoic formations to the northwest by a thrust fault or an unconformity (Neathery, 1973), and are separated on the southeast from higher rank metamorphic rocks of the Piedmont by faults and gradational contacts. Ages for the Talladega beds seem to range from Middle Ordovician to Carboniferous (Shaw, 1973).

The phyllites dip monoclinally southwestward. We observed a typical exposure along State Highway 149 about 1.6 km east of Sylacauga. The beds have a strike of N40E, dip 35SE. Minor jointing is present and crinkle-folds allow determination of structural axes. Quartz spindles and veinlets fill crinkle-fold axes. The vegetation pattern is uniform until Talladega Mountain is reached. This topographic feature is underlain by massive arkosic sandstone, mapped as the Cheaha Sandstone Member of the Talladega Slate. The sandstone is clearly identifiable on photographs and imagery, and probably supports a distinctive flora. Preliminary observation suggests that the Jemison Chert (Devonian) and Erin Slate (Carboniferous) may also support a plant population that is sufficiently distinct to identify the outcrop pattern of the rock units.

It appears that photogeologic methods used in conjunction with close ground control could contribute much to solving longstanding questions regarding the relationship of the Talladega beds to other rock units of the Appalachian and Piedmont provinces

B. Rich Hill, Crawford County, Georgia

Two related outcrops of Upper Eocene limestone, known as the Rich Hill locality, are very intriguing. The area was described by Veatch and

Stephenson in 1911 and has been visited by subsequent generations of geologists, most of whom have puzzled over the preservation of these beds at a considerable distance from the nearest rocks of equivalent age (Fig. 21).

The Rich Hill locality is in Crawford County, about 4 km east of Knoxville. The hill is capped by red sand and clay which has been assumed to be non-marine beds of the Jackson group correlative with the Irwinton Sand Member of the Barnwell Formation. The nearest Irwinton beds are about 22 km to the east. Beds of definite Jackson age include about 4 m of purplish and yellow sand overlying 6.5 m of jointed, laminated clay, identified as Twiggs Clay. Beneath the clay is 6 m of soft, cream-colored or white limestone, highly fossiliferous and typical of the Tivola bryozoan limestone facies of the Ocala Formation. This overlies a tan-colored, soft basal sand in which we found numerous fragments of whale bones. We correlate this sand with the Clinchfield Sand Member of the Ocala. The Jackson beds rest on white kaolinitic clay and sand of Cretaceous age which has been mapped as Tuscaloosa Formation. Metamorphic rocks of the Piedmont province are present no more than 7 km to the north of Rich Hill.

Immediately south of the exposure described above is a small hill of limestone about 2 hectares in area, with very little soil cover and resting directly upon Cretaceous sandy clay. There is no Clinchfield Sand present between the Tivola Limestone and the Cretaceous clays.

It has been assumed that the Rich Hill beds represent an erosional outlier and that they indicate a much wider extension of Jackson seas than the present outcrop pattern shows. We concur in the latter interpretation, but do not believe the beds are preserved as simple outliers. Topographic relations indicate that Cretaceous sediments occur at higher elevations than the Eocene beds, and the limestone and blocky clay do not occur on the north side

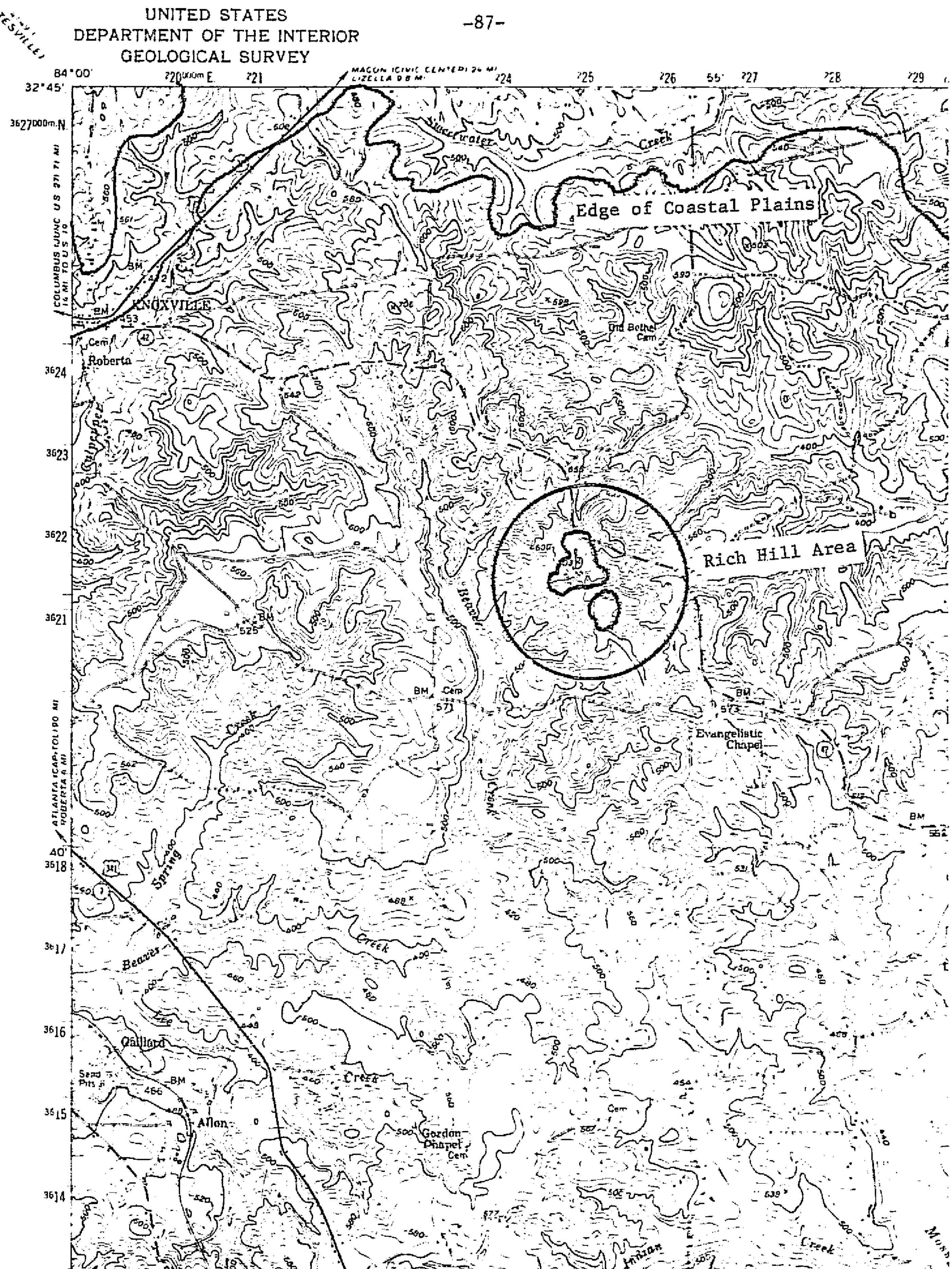

Fig. 21. Location Map of Rich Hill Area.

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of Rich Hill. We believe that careful mapping would show that the Jackson beds are preserved because they moved down slope on the Cretaceous clays and are preserved as landslide remnants in former valleys cut into the Cretaceous and younger beds.

Quarrying of the larger limestone body occurred prior to 1940, so it is difficult to be certain how much this has influenced the present vegetation pattern. Today, both limestone areas are nearly bare, and the most common trees growing on them are Redbud (Cercis canadensis). There is a dense stand of Pine-Oak forest surrounding the limestone outcrops and the boundary between forest and the Redbud-grass area is very sharply defined.

The limestone areas show up clearly on Landsat imagery and would undoubtedly stand out on all other types of remote sensing documents.

C. Inner Margin of Coastal Plain

In Georgia west of the Ocmulgee River the boundary between the Coastal Plain and Piedmont geological provinces is clearly defined on all remote sensing media. It shows up especially well on springtime Landsat imagery (e.g., 13 Apr 73 E-1264-15445-5) band 5, or composite band 5-red and band 7-blue. Light color tones dominate in the Coastal Plain, and the boundary with the biotite gneiss of the Piedmont is easily picked. Vegetation maps also show this line as a major boundary (Fig. 22).

Lithologic units within the Piedmont can sometimes be defined. This seems to be the case, however, only where there is a definite difference in composition of the country rock, and therefore a distinctive soil development. For example, on the Landsat sheet cited above, the trend of the Hollis Quartzite in the Pine Mountain area is readily traced, and mica and sericite schists or granitic intrusions can be separated if they are in contact with the biotite gneiss.

It seems likely that the vegetation cover is a significant factor in producing the tonal distinctions. Within the upper Coastal Plain area long the Flint River there is no fundamental difference in chemical and mineral composition between the Cretaceous or Tertiary sediments and the sands and clays of the river alluvium. There is, however, a consistent endemic flood plain vegetation along the river, and the resulting Landsat pattern is distinct. Comparison of the dark tones of the flood plain shows very close correlation with the Quaternary alluvium pattern of the new geological map (Georgia Geological Survey, 1976).

Time did not permit us to make further comparisons. It appears likely that tonal signatures could be established for the major rock units. The value of this procedure would lie in an ability to check the geological mapping and - perhaps of greatest significance - to point out anomalous tonal areas that might reflect relatively minor geological occurrences not obvious in other mapping programs.

X. EVALUATION OF MEDIA

Evaluation of the effectiveness of remote sensing media should include consideration of equipment that may be useful, or even necessary, for interpreting the various types of documents. In the discussion that follows, we have dealt only with types of documents and equipment that we have used or examined during the work on the project.

A. Landsat Imagery

Detailed technical descriptions of the Landsat system may be found in several publications, including the Manual of remote-sensing, published by the American Society of Photogrammetry (Reeves, 1975) and the Data users handbook, issued by NASA Goddard Space Flight Center (1971).

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D SUN EL54 AZ126 190-3680-N-1-N-D-2L NASA ERTS E-1264-15445-5 02
(Landsat Imagery)

Fig. 22. Inner Coastal Plain along Flint River. Landsat 1:500,000-scale print, Band 5.

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The Landsat multispectral scanner measures instantaneous electromagnetic radiation (EMR) flux from an area 79 by 79 meters. The measurement is made along a line 185 km long. With overlap, areas 79 m by 57 m result as a basic image unit called a pixel (picture element). Approximately 2250 lines produce a Landsat frame 185 km by 178 km in area, and about 7.3 million pixels form a mosaic covering 32,930 km^2. This represents a scale resolution of 221.7 pixels/km^2, or an area of about 4511 m^2 per pixel, which means that each pixel is roughly 1.1 acres.

The amount of energy recorded determines the pixel brightness and is a function of the percent of each type of surface material within the area and the amount of EMR reflected by each material. Four wavelength bands are recorded simultaneously:

Band 4: 0.5 to 0.6 μm (visible green) (μm = micrometer = 10^{-6} meter)

Band 5: 0.6 to 0.7 μm (visible red)

Band 6: 0.7 to 0.8 μm (reflected solar infrared)

Band 7: 0.8 to 1.1 μm (reflected solar infrared)

In the project areas we find Band 4 to be useful chiefly in observing high-reflectance objects, such as highways, airstrips, and cities. Band 5 is best for emphasizing tonal differences related to vegetation and soils. Bands 6 and 7 emphasize water areas, and Band 7 is best for topography.

We used the International Imaging Systems (I^2S) viewer at MSFC laboratories, and found that various combinations of projected band composites and color filters enhanced geological or vegetative features. This viewer-projector can accept four individual 70-mm transparencies in a film chip holder. We feel there is some advantage in using positive rather than negative transparency chips. One benefit is that the border area is dark on the positive chips, thus reducing extraneous light around the edges of the

field. No set combination of bands and filters appears to be best for all areas, and we can only recommend that an investigator experiment to determine which combination works best for each area and image objective.

B. Skylab Photography

The Skylab camera system has better resolution than most aerial cameras, and at an unenlarged scale of 1:950,000 it has a minimum detection area of about 400 m^2.

C. Reconnaissance Photography

Like the Skylab frames, high-altitude reconnaissance photography has regional coverage and relatively good resolution. The 1:120,000-scale frames have a ground detection factor of about 20 m^2.

D. Color Infrared Photography

For most of our work the color infrared (CIR) photography, at a scale of 1:24,000, proved most useful. It was flown by MSFC in February and April, thus providing winter and spring conditions of vegetation. Healthy vegetation is a much stronger reflector in the near infrared than in the green portion of the spectrum, so it appears in various hues of red on the film. With some experience the interpreter can recognize what the false colors represent in terms of vegetation and soil or rock conditions. Ground detection resolution is about 1 m^2, which allows identification of individual trees. Reflectance contrast allows discrimination of such things as conifers from hardwoods, dying from healthy plants, and presence of soil moisture from dry earth.

E. Multispectral Photography

Four-image multispectral coverage was flown in conjunction with the CIR photography by MSFC and covers most of the project areas. Unfortunately, the quality of this photography was not what we had hoped, and it

proved to be less useful than the infrared frames. We are not able to make a proper evaluation of the system.

XI. ACKNOWLEDGEMENTS

We wish to acknowledge the technical and advisory support of the Earth Resources Office, Data Systems Laboratory, at Marshall Space Flight Center, Alabama. John Bensko, geologist for this office, served as contracting officer's representative and assisted us in many ways throughout the course of the study.

Various agencies of the Georgia Department of Natural Resources have cooperated in furnishing copies of unpublished reports and maps. We are indebted to the Division of Earth and Water, which includes the Georgia Geological Survey, and in particular Sam M. Pickering, Jr., State Geologist and Director. This Division has been helpful in making results of their researches available and in arranging with landowners for our field investigations.

The staff of the Albany-Dougherty County Metropolitan Planning Commission made maps and aerial photographs available.

We have found property owners, mine or quarry operators, and the staff of government agencies at all levels to be courteous and cooperative in furnishing information and allowing us access to carry out the field work.

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